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CONVERGENCE STUDIES IN THE MID-CONTINENT REGION[1]

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ABSTRACT

The object of this paper is to direct attention to the northwestward convergence, or decreasing thickness, of the Pennsylvanian rocks of eastern Oklahoma, as a very important phase of structural geology and stratigraphy. This convergence is considered from the standpoint of (1) its amount, (2) its application to some common geological problems such as correlations, local structure, depths to lower formations, surface structures, and subsurface faulting, and (3) its comparison with the convergence of north Texas. The conclusion is drawn that the Bend Arch and the Ozark uplift have a common origin and are to be correlated as part of the same structural unit.

INTRODUCTION

The southeastward thickening of the Pennsylvanian formations in eastern Oklahoma is described in practically all of the early geological literature dealing with this region. During recent years thousands of drill holes have penetrated the Pennsylvanian rocks in search of oil in the underlylng Mississippian and Ordovician formations, thereby furnishing a great mass of additional information on this phenomenon. The object of this paper is: (1) to consider quantitatively this southeast divergence, or northwest convergence, of the Pennsylvanian formations, (2) to point out some of the applications of convergence to every day geological problems, and (3) to indicate the probable correlation and origin of the Bend Arch of Texas and the Ozark uplift of Missouri and Oklahoma, based on convergence studies.

In regional work on convergence, it is necessary to use formations

[1] Read before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, April 25, 1927.

which are regular, readily distinguished in well logs, and common to wide areas. In Oklahoma the Calvin series and the Oswego lime (middle Pennsylvanian) furnish one upper-datum horizon that satisfies all of the requirements. Their equivalent in north-central Texas is the Palo Pinto

		NORTH CENTRAL TEXAS	ARDMORE BASIN	SOUTH CENTRAL OKLAHOMA	NORTH EASTERN OKLAHOMA
PENNSYLVANIAN	CANYON	CADDO CREEK FM. BRAD FM. GRAFORD FM.	HOXBAR FM.	SEMINOLE CONGL. HOLDENVILLE SH. WEWOKA FM.	
		PALO PINTO LS		WETUMKA CALVIN SS. — CALVIN SERIES	FT. SCOTT OSWEGO
		STRAWN FM.	DEESE FM. (UPPER GLENN)	SENORA FM. THURMAN SS. BOGGY SH. SAVANNA SS. McALESTER FM. HARTSHORNE SS.	CHEROKEE SH.
		MILLSAP	CUP CORAL MEMBER (MIDDLE GLENN)	ATOKA FM.	WINSLOW FM.
		SMITHWICK SH. MARBLE FALLS LS	OTTERVILLE LS. (LOWER GLENN)	WAPANUCKA LS.	MORROW LS.
MISS.		BARNETT SH.	CANEY SH.	PITKIN LS. CROMWELL SS.	PITKIN LS.

FIG. 1.—Correlation table of Pennsylvanian formations found between the Calvin series-Oswego lime-Palo Pinto lime, and top of Mississippian in Oklahoma and north Texas. The changes in thickness of these intervening formations form the basis of this paper.

limestone, which is equally satisfactory and makes possible a direct comparison between the two states. In Oklahoma, the "Wilcox" sand (Ordovician) and any of the associated contacts, furnish excellent deep-datum horizons. They are separated from the Oswego lime and the Calvin series by at least three unconformities, and therefore the changing interval between these two horizons is the sum of several separate convergences. The

Pennsylvanian-Mississippian contact is used as a datum by mapping the Morrow and Wapanucka limestones (basal Pennsylvanian), the Cromwell sand (Pitkin-Mississippian) in Oklahoma, or the Marble Falls limestone (basal Pennsylvanian) in Texas.

Figure 1 gives the lower Pennsylvanian correlations used, most of which are taken from the United States Geological Survey and Oklahoma Geological Survey publications, and on which there is more or less general agreement. Bruce H. Harlton, of the Amerada Petroleum Corporation, from microscopic work, modified somewhat the correlations used in the Ardmore basin.

The "Calvin series," as a subsurface term, originated during the development of the Cromwell field in T. 10 N., R. 8 E., Seminole County, Oklahoma. It is the name given to a series of three or four sands which are found at depths ranging from 1,700 to 2,000 feet, and which form a good marker in most logs. At the outcrop on the east, as shown on the areal map of Oklahoma, the highest member of this series is the basal sand of the Wewoka formation. The two sands occurring below the highest member are the equivalent of the Calvin sand on the outcrop. Since the term "Calvin series" has come into general use, it is so used here, but with the understanding that it actually includes formations up to and including the basal sand of the Wewoka formation.

The correlation of the Wetumka shale with the Fort Scott-Oswego lime has been made by Edward Bloesch.[1] This correlation is approximately in agreement with that obtained in subsurface work.

The work on convergence has been carried on by the writer during the past three years, mainly while in the employ of the Gypsy Oil Company in the Okmulgee district. The writer wishes to acknowledge his indebtedness to Earl Colton, K. C. Heald, W. B. Wilson, and W. E. Bernard for many helpful discussions of the subject.

CONVERGENCE IN EAST-CENTRAL OKLAHOMA

The thickness of the formations between the Calvin series (Middle Pennsylvanian) and the Viola and "Wilcox" formations (Ordovician), as found in oil wells 6 miles northwest of Okmulgee, ranges from 1,800 to 2,000 feet. The formations, which crop out between this point and the Ouachita and Arbuckle mountains, have at the outcrop a total maximum thickness of nearly 22,000 feet. If extended southeast to include the Stanley and Jackfork formations of western Arkansas, this latter thick-

[1] Edward Bloesch, "Fort Scott-Wetumka Shale Correlation" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 810–11.

ness is further increased. This southeast thickening, particularly of the Pennsylvanian rocks, averages about 250 feet per mile. It has been mentioned in several published works in connection with the geology of southeastern Oklahoma and is generally ascribed to the thickening of the formations as they pass into the Ouachita-Arbuckle geosyncline.

The southeast thickening shown in Figure 2 extends through most of the oil-producing territory of east-central Oklahoma. This is shown in

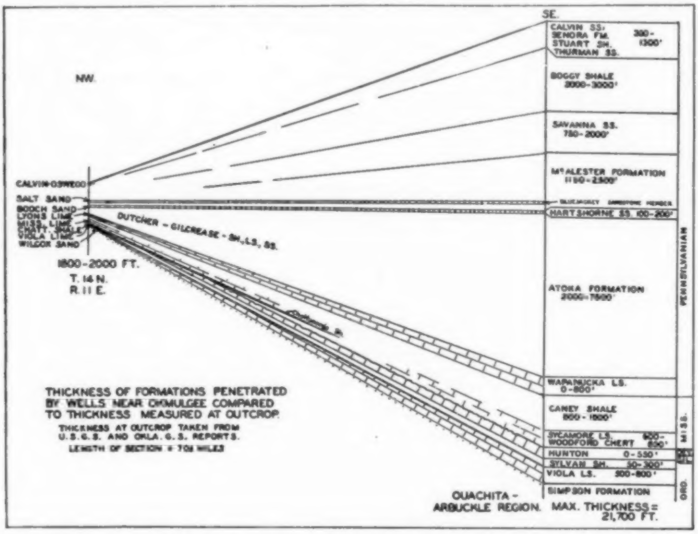

FIG. 2.—Chart showing southeast thickening of formations between wells drilled northwest of Okmulgee and the outcrop of the same formations toward the Ouachita-Arbuckle mountains. Based on United States Geological Survey and Oklahoma Geological Survey reports.

Figures 3*A* and 3*B*, which are cross-sections through the Cromwell and Papoose fields in Seminole and Hughes counties. Figure 3*A* shows the logs arranged on a sea-level datum, indicating the present structure. Figure 3*B* shows the same logs arranged with the top of the Calvin series as a datum, and shows the northwestward convergence of all of the formations. Throughout a large area in this vicinity the northwestward convergence between the Calvin series and the Cromwell sand is very regularly 90 feet per mile. This convergence, as shown in the diagram, is evenly distributed between any two beds, although the lower part of the sec-

tion, particularly the Gilcrease formation, has in general a more rapid northwestward decrease in thickness than the younger formations.

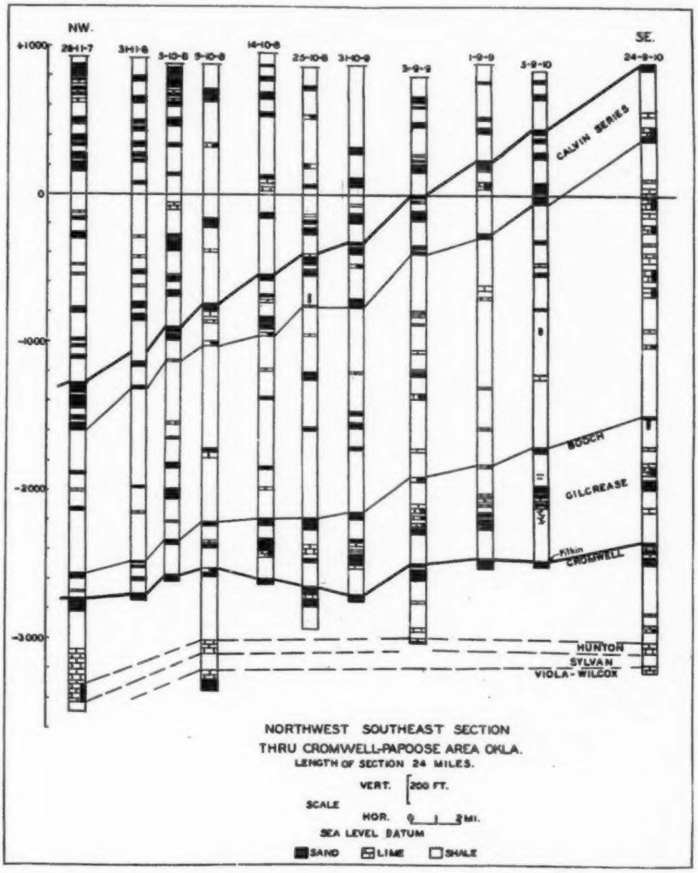

FIG. 3A.—Cross-section through Cromwell and Papoose fields, Oklahoma, with logs arranged on sea-level datum.

Assuming that the Calvin series was level when deposited, Figure 3*B* also may be considered as showing the structure of the Cromwell sand at the time of the deposition of the Calvin series.

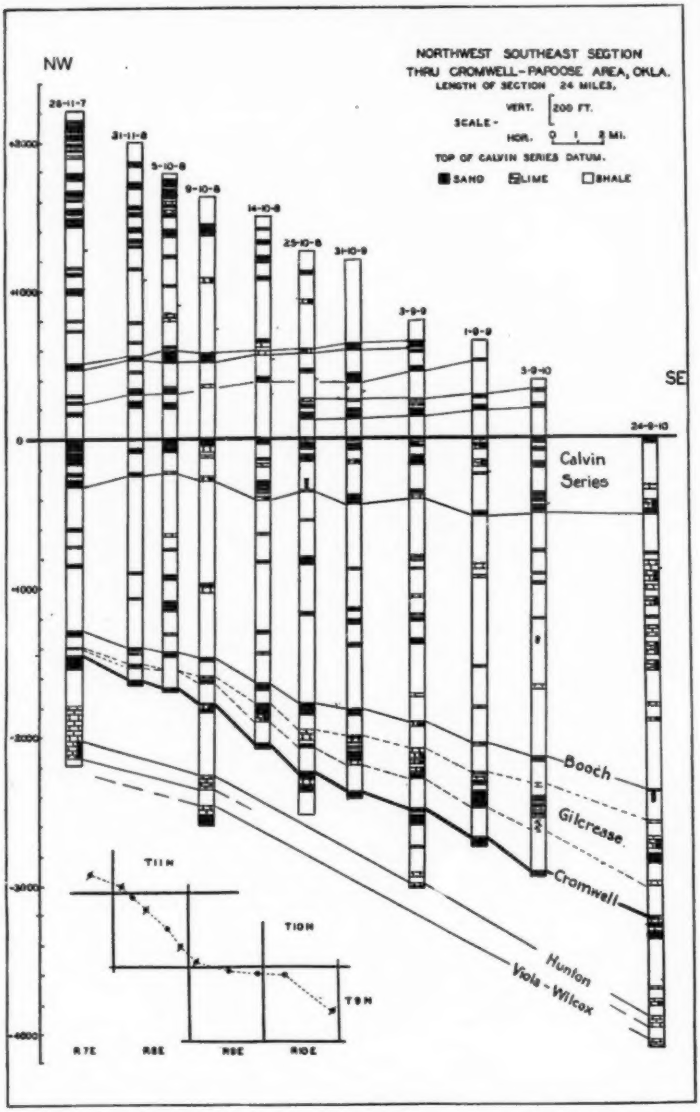

FIG. 3B.—Same as Figure 3A except that logs are arranged with top of Calvin series as a datum. In a distance of 24 miles the formations between the Calvin series and the Cromwell sand have thinned from 3,200 feet to 1,425 feet, or at an average rate of 77 feet per mile.

Figures 4*A* and 4*B* are similar to Figure 3, except that they are farther north, and show the northwestward thinning between the Oswego lime and the "Wilcox" sand. Figure 4*A* is the present structure, having

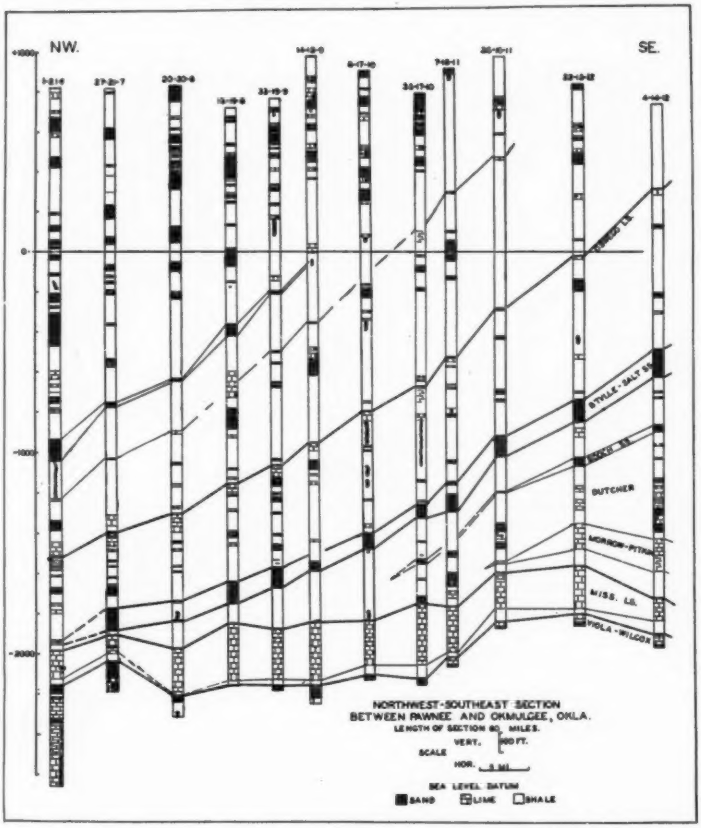

FIG. 4A.—Cross-section between Okmulgee and Pawnee, Oklahoma, with logs arranged on sea-level datum.

sea-level datum. Figure 4*B* shows the same logs as Figure 4*A*, except that they are arranged with the top of the Oswego lime as a datum. This cross-section shows the progressive northwest overlap of the younger formations onto a Mississippian land area to the northwest. Thus the

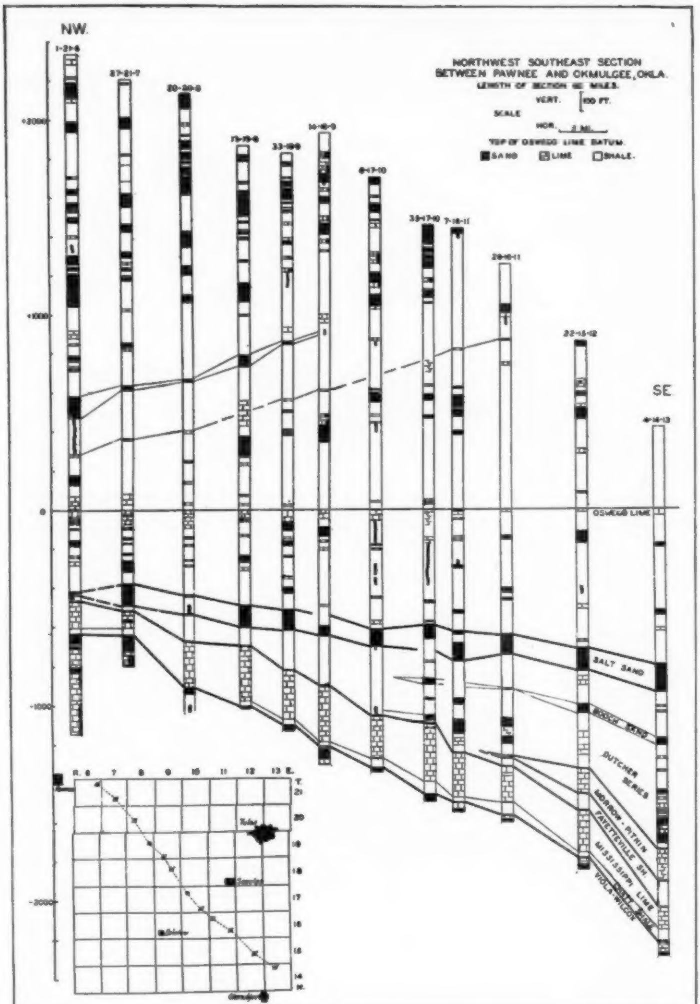

FIG. 4B.—Same as Figure 4A except that logs are arranged with Oswego-Fort Scott lime as datum. In a distance of 60 miles the formations between the Oswego-Fort Scott lime (Pennsylvanian) and the Viola lime (Ordovician) have thinned from 2,220 feet to 610 feet, or at an average rate of 26 feet per mile. This northwestward convergence increases toward the Okmulgee area, where it reaches 75 or 80 feet per mile. This figure also shows the progressive northwestward overlap of the intervening formations as the early Pennsylvanian sea advanced onto the Mississippian land to the west. It also represents the structure of the Mississippian and "Wilcox" at the time the Oswego lime was deposited.

Bartlesville-Salt sand extends much farther northwest than the Booch sand, and the Booch farther than the Dutcher, and the Dutcher, in turn, farther than the Morrow lime.

Here, also, Figure 4*B* may be taken as representing the structure of the "Wilcox" sand and of the Mississippian rocks at the time the Oswego lime was deposited.

The available information on eastern Oklahoma is assembled in Figure 5, which shows contours connecting points of equal interval between the Calvin series-Oswego lime (Pennsylvanian) and the Viola and "Wilcox" formations (Ordovician). The contour interval is 500 feet. Fairly definite control is obtainable on the southeast side up to the 5,000-foot contour. The short contours extending beyond this point are based on the surface measurements shown in Figure 2. On the other side, or northwestward, the control is very good, and the rate of convergence gradually decreases up to the 1,000-foot contour. From here northwest there is little or no regional convergence over an area extending beyond Ponca City. In this area the interval ranges between 300 and 900 feet and is irregular. There are several irregularly shaped, closed "highs" and corresponding closed "lows," giving a decided change to the contour pattern from the uniform spacing and direction farther southeast.

In Figure 5, also, the contours may be taken as representing the structure of the "Wilcox" formation at the time the Calvin series–Oswego lime was deposited. This was a high, rolling area to the northwest, which gradually passed into a southeast-dipping monocline on the southeast, the dip increasing up to 300 feet per mile in the McAlester-Atoka region. A structural relief of 10,000 feet or more is indicated in the pre-Pennsylvanian formations during Calvin-Oswego time.

A regular northwestward convergence in the Pennsylvanian formations is, therefore, present over a large area in eastern Oklahoma and is a constant factor to be considered in all the structural and stratigraphic problems within this area. The second part of this paper deals with some of the applications of this convergence to practical geological problems.

SOME APPLICATIONS OF CONVERGENCE

USE OF CONVERGENCE IN CORRELATING

Convergence is of great assistance in correlating the deeper formations when development is proceeding outward from known areas. Figure 6 shows logs of two tests, one in the Cromwell field and the other in the Papoose field. Without intervening wells, and without a knowledge of the

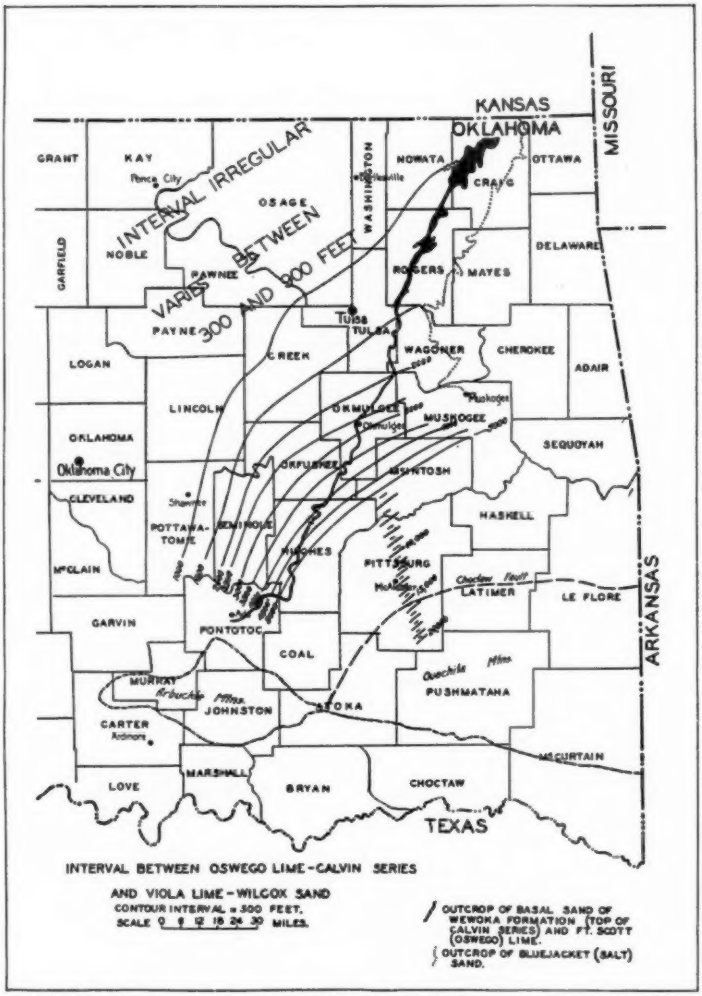

Fig. 5.—Isopachous map showing the interval between the Calvin–Fort Scott horizon (Pennsylvanian) and the Viola "Wilcox" (Ordovician). The contour interval is 500 feet. Assuming that the Calvin–Oswego formation was level when deposited, the contours may be taken as representing the structure of the Viola "Wilcox" at the time of the deposition of the Calvin–Oswego formation.

regional convergence toward the northwest, it would be difficult to make the correct correlation. These logs are both taken from the cross-sections shown in Figures 3*A* and 3*B*.

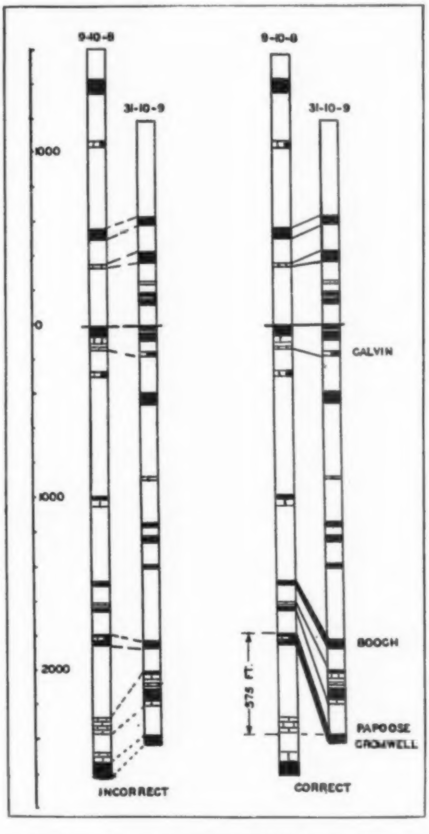

FIG. 6.—Example of use of convergence principle in correlating well logs. Without a knowledge of convergence, without the intervening logs, or without well cuttings and paleontological evidence, the correlation shown on the left would be the natural correlation of the formations below the Calvin series. The correct correlation, on the right, involves a thinning of 575 feet of the pre-Calvin sediments in a distance of 6 miles, and is the normal rate of convergence through this area. These two logs are in the cross-section shown in Figure 3.

APPLICATION OF CONVERGENCE TO LOCAL STRUCTURE

Figure 7, *A*, *B*, *C*, and *D*, illustrates several applications of convergence to local structure. The structure mapped is the Garrison field, 5 miles south of Okemah, Okfuskee County, Oklahoma. Oil and gas production

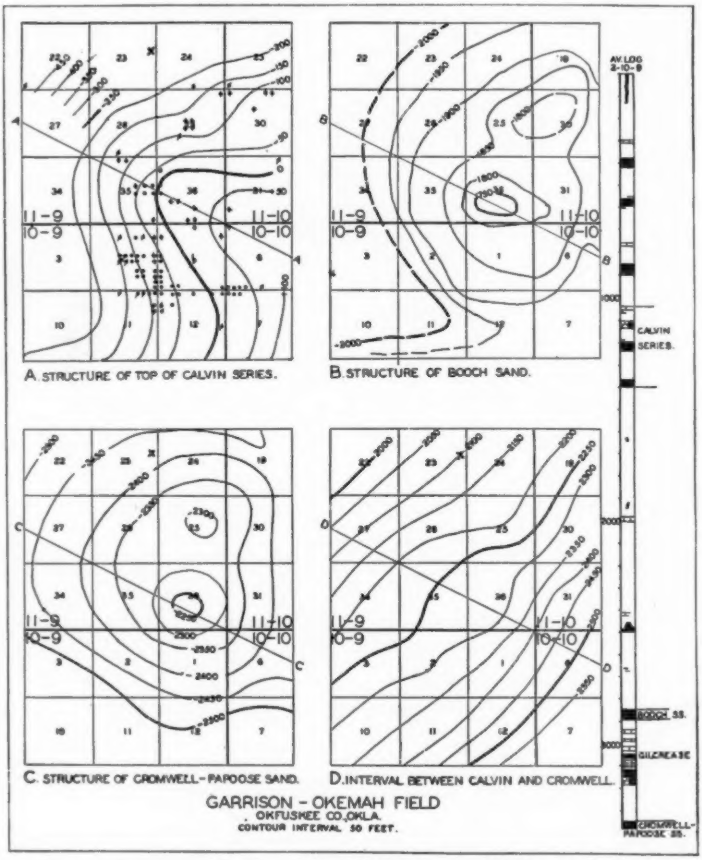

FIG. 7.—Structure of Garrison field, Okfuskee County, Oklahoma, showing apparent progressive steepening and northwest shifting of structural axis on depth. *D* is the difference between *A* and *C* and can be taken as the structure of the Cromwell sand at the time the Calvin series was deposited. Since *D* is the normal northwest convergence of the pre-Calvin Pennsylvanian formations, this convergence is the cause of the steepening at depth.

has been obtained from the Gilcrease formation and the Cromwell sand. Gas has been found in the Hunton lime and in the "Wilcox" sand on the top of the structure.

A is the structure of the Calvin series found at depths ranging from 1,000 to 1,100 feet, and shows it to be a terrace or nose structure. This is approximately the same as the structure found at the surface, but is slightly sharper. The surface structure in this particular area is somewhat obscured by loose surface sand deposits.

B is the structure of the Booch sand found at depths ranging from 2,800 to 2,850 feet, and shows that at this depth the structure is closed by about 125 feet.

C is the structure of the Cromwell-Papoose sand, from 3,400 to 3,450 feet, and shows that at this depth the closure has increased to about 175 feet.

These three maps show the apparent progressive sharpening on depth and the northwest shifting of the subsurface fold, which is typical of structures through eastern Oklahoma.

D shows the interval between the Calvin series and the Cromwell sand, or the difference between structures *A* and *C*. In general, the convergence contours cross the structure without change in direction, the principal variation from normal being a closer spacing on the southeast side of the structure. *D* can also be considered as showing the structure of the Cromwell sand at the time the Calvin sand was deposited, the structure at that time being a nearly uniform southeast dip of 90 or 100 feet to the mile.

Since the thickening of the Pennsylvanian formations through this area is nearly uniform toward the southeast, deposition must have proceeded without interruption. If folding had occurred during deposition, or if there had been a buried hill underlying and causing the present structure, the sediments would have been thicker down the flanks of the fold, resulting in a closed convergence contour pattern.

Progressive folding or settling around a buried hill as a cause of this structure is further disproved when the convergence contours are considered as the structure of the Cromwell sand at the time the Calvin was laid down.

Actually, the amount of folding of the Calvin sand, the Booch sand, and the Cromwell sand is very nearly the same, as can be seen by Figure 8 *A*, a cross-section across the structure from northwest to southeast. The sharpening at depth is in the main apparent only. This is due to the fact that the present structure-contour map is based on sea-level, an

arbitrary datum, while the true amount of folding is measured from the natural datum or the average regional dip of the surrounding area. In other words, the same dome fold will contour, sea-level datum, as an east-pitching nose, a dome, or a west-pitching nose depending on whether the natural datum or regional dip is east, flat, or west. Figure 8 *B* illustrates

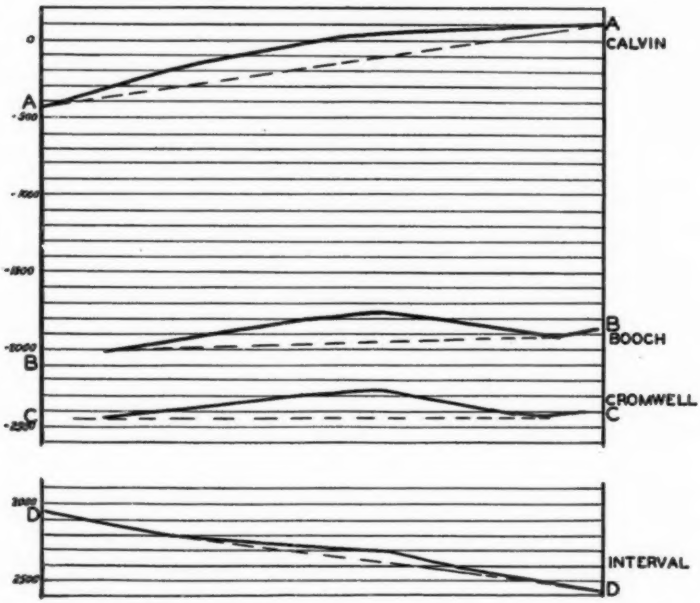

FIG. 8A.—Cross-section of Garrison field structure shown in Figure 7 along lines *A–A*, *B–B*, *C–C*, and *D–D*. The folding of the Calvin series is almost as much as the folding of the Cromwell sand, the difference being the small fold shown in the convergence, or *D–D*. For this reason the steepening at depth is more apparent than real, and is due to convergence.

the principle and shows why converging strata alone explain the steepening at depth and the shifting of the subsurface folding which are shown in Figure 7.

Since the folding of the Cromwell sand and of the Calvin series is of the same magnitude, all of the folding must have taken place after the deposition of the Calvin series, and also after the surface beds were deposited.

We have here then a surface terrace or nose structure overlying a dome with about 175 feet of closure, which was folded once, and that after the youngest formations were deposited. The northwest shifting of the deep structure and the apparent sharpening of the structure at depth are due to the convergence between the younger and the older beds.

In working with the interval between the Calvin-Oswego (Pennsylvanian) and the "Wilcox" (Ordovician), the convergence pattern is not as regular as that shown in Figure 7 *D*. In fact, there is a rather general

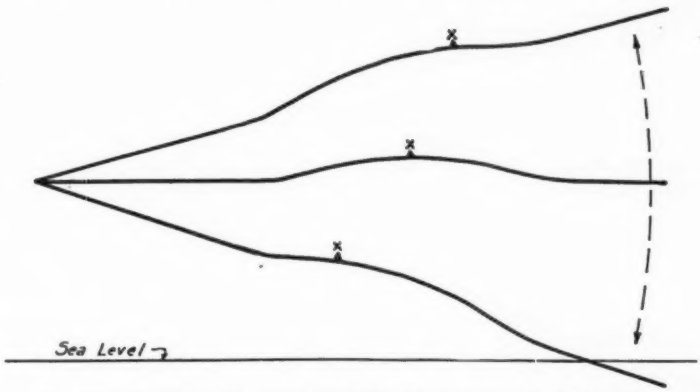

FIG. 8B.—Shows how the same dome fold will contour, sea-level datum, as a west terrace or nose, a dome, or an east-pitching terrace or nose, depending on the regional tilt or dip of the area. X is the highest part of the structure in each case and shows the shifting on depth toward the direction of convergence.

thinning of the section over the top of the "Wilcox" structures. This is shown in Figure 10, Secs. 19 and 20 and Secs. 31 and 32, T. 15 N., R. 14 E., and Secs. 26 and 27, T. 14 N., R. 13 E. The convergence pattern forms east- and southeast-pitching noses or terraces, which, in the absence of surface well elevations, furnish good indications of a folded area. At best, however, this pre-Oswego folding accounts for but a minor part of the steepening on depth or shifting of the deep structure. Convergence is the dominating cause of such phenomena. Most of these noses are due to folding which took place prior to the deposition of the Pennsylvanian, or to the folding which occurred at the time of most of the subsurface faulting, that is, post-Mississippian and pre-Booch.

In applying convergence to local problems, a common source of error is the correction of the cable or drilling measurement by the steel-line

measurement. For example, when the Oswego-Viola interval is being mapped, a drilling well may not have a steel-line measurement taken until the top of the Viola is reached. The elevation of the Viola is then accurate, but the interval between the Oswego and the Viola includes all the error in the measurement of the hole. This may amount to 25 or 50 feet, and gives a marked irregularity to the otherwise evenly spaced convergence contours and may lead to erroneous conclusions. The safer practice, unless special knowledge is available on the amount and location of the correction, is to consider only those irregularities in the convergence pattern which depend on more than one well.

USE OF CONVERGENCE IN ESTIMATING TOP OF SAND

It is quite evident that when any well-drilling, as at *X* in Figure 7 *A*, reaches the top of the Calvin series, the convergence contour passing through this location will give the distance to the top of the deep datum formation, in this case the Cromwell sand. The structure of the lower horizon can thereby be estimated with much less error than by correlating with the log nearest it, regardless of its direction.

APPLICATION OF CONVERGENCE TO SURFACE STRUCTURE

Throughout most of the Mid-Continent region, where the folding at the surface is relatively gentle, the pitch of the surface folds is more or less evenly divided between a southwest, west, and northwest direction. Depending on the direction of the convergence alone, the subsurface structures below different types of surface structure have widely different values.

Figures 9*A* and 9*B* show, respectively, southwest (*A*) and northwest (*B*) pitching surface folds (short dashed lines) from which is subtracted a constant northwest convergence (light solid lines). The resultant structure of the subsurface beds (heavy solid lines) is merely a nose with a sharp south dip in example *A*, while it is automatically closed in example *B*. Thus, other things being equal, convergence here has greatly diminished the value of one of two surface folds both of the same magnitude and differing only in the direction of pitch.

The conditions shown in Figure 9 are typical of the Okmulgee district, and drilling has shown that most of the subsurface domes underlie surface folds of the general type shown in example *B*. Here the north dip on the surface gives north and northeast dips on the lower formations, west and southwest dip on the surface gives a steeper southwest dip below, and the southeast divergence gives the closure on the east and southeast sides of

the subsurface anticline. In this manner, the critical dip of the surface structure of any area, where the convergence direction is known, may be worked out.

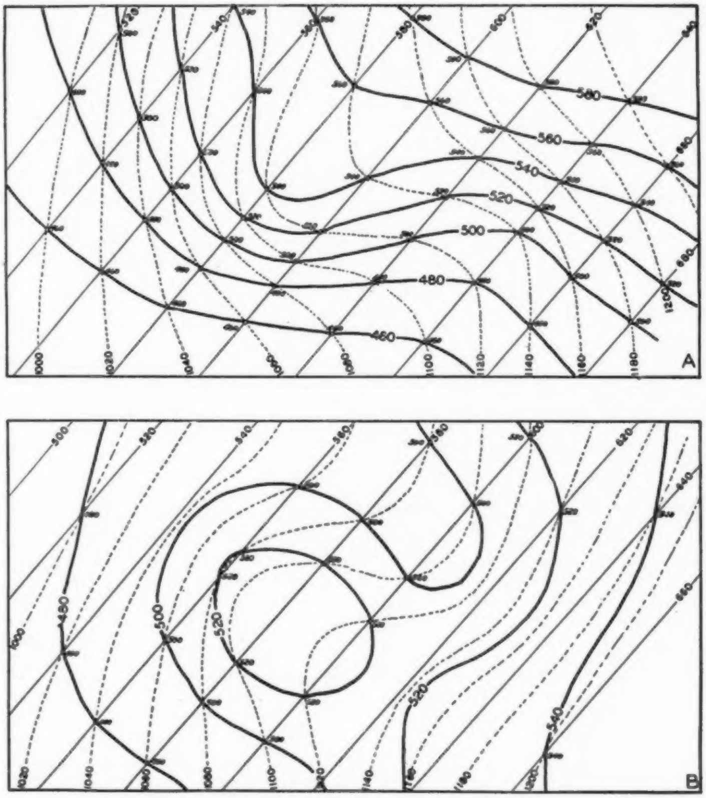

FIG. 9.—Effect of convergence on two types of surface folding. *A* shows a southwest-pitching surface fold (light dashed lines) and *B* shows a northwest-pitching surface fold (light dashed lines), both passed through a uniform northwest convergence of the underlying formations (light solid lines) resulting in an increased south component, *A*, and a closed structure, *B*, on the lower formations (heavy solid lines).

In more general terms, it may be stated that the surface fold of greatest value at depth is the one which pitches in the same direction as the subsurface beds are converging. Also, the greater the rate of convergence,

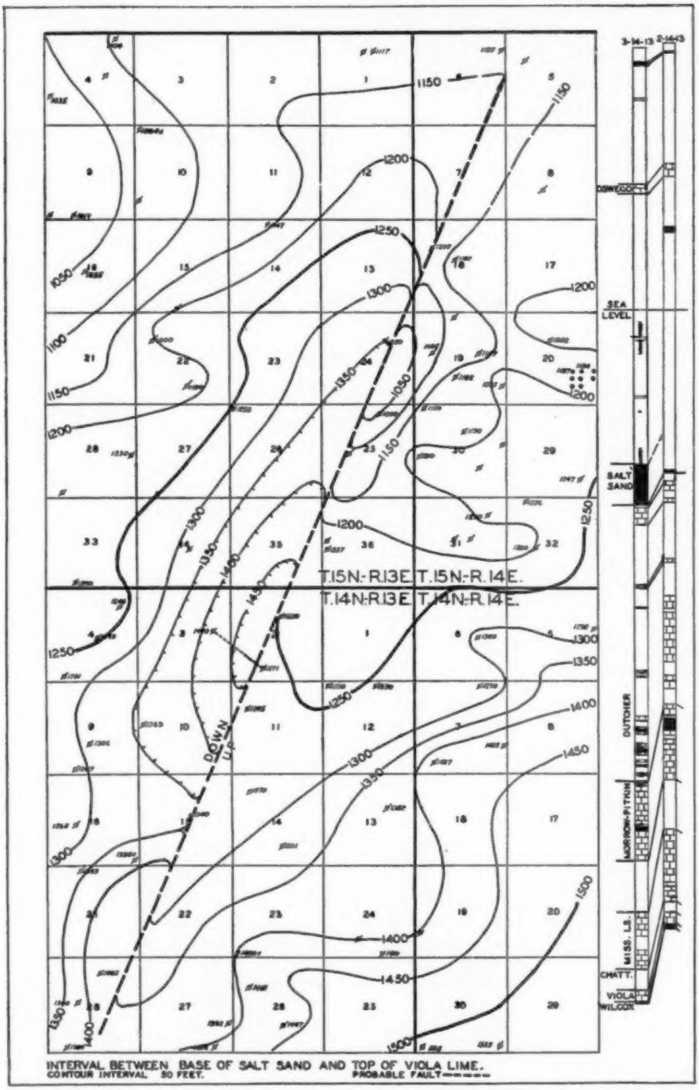

FIG. 10.—An area in Okmulgee County, Oklahoma, where the interval between the Salt sand (Pennsylvanian) and the Viola lime (Ordovician) changes abruptly, thereby suggesting subsurface faulting. These contours, when considered as the distance of the Viola lime below the Salt sand, may be used as the structure of the Viola at the time the Salt sand was deposited.

the less surface structure necessary to automatically give a closed structure on depth, and the greater the subsurface shifting of the axis.

APPLICATION OF CONVERGENCE TO SUBSURFACE FAULTING

Faulting which occurred at the end of the Mississippian or in early Pennsylvanian time is difficult to detect in most cases. In only a few places, as in the Tonkawa and Wewoka oil fields, can it be determined by closely spaced wells. It is undoubtedly a much more common structural feature in Oklahoma than is generally supposed, and where the control is relatively poor, convergence maps are of help in suggesting the presence, location, and trend of such buried faults.

As has been described, the Pennsylvanian formations are converging uniformly toward the northwest. Where this regular convergence is abruptly increased or decreased along a line more than 2 or 3 miles in length, subsurface faulting is probable. Generally, in such cases the convergence contours have a different strike on either side of such a line.

This change in strike and the abrupt change in interval along a line 10 or 12 miles long is shown in Figure 10. A reasonable interpretation of the evidence in this area is a fault, downthrown from 200 to 300 feet on the west side, and having occurred before the deposition of the Glenn or Salt sand and after the deposition of the Viola limestone. By using, progressively, beds older than the Salt sand and younger than the Viola lime, the age of the particular fault shown in Figure 10 can be determined as being pre-Booch and post-Dutcher, or early Pennsylvanian.

Relatively high structural relief, characterized by steep dips and sharp folds, is the normal expectancy in contouring the structure of the Ordovician rocks. Without using convergence, therefore, the area shown in Figure 10 could have been contoured on the top of the Viola lime, sea-level datum, without even suspecting the presence of a fault.

COMPARISON OF CONVERGENCE OF PENNSYLVANIAN OF NORTH TEXAS AND OF OKLAHOMA

NORTH-CENTRAL TEXAS

The Strawn formation in north-central Texas and along the Bend Arch thins toward the west. This has been described by Hager,[1] Plummer, Moore,[2] and others. It is well shown in Plummer's report[3] by a cross-

[1] Dorsey Hager, "Geology of the Oil Fields of North Central Texas" (1918), *Amer. Inst. Min. Eng.*, Vol. 61 (1920), pp. 526–28.

[2] Frederick B. Plummer and Raymond C. Moore, "Stratigraphy of the Pennsylvanian Formations of North Central Texas," *University of Texas, Bull. 2132* (1921).

[3] *Op. cit.*, Plate IX, opp. p. 56.

section across Palo Pinto and Stephens counties. Figure 11 is in the main adapted from this cross-section and shows the relations existing between

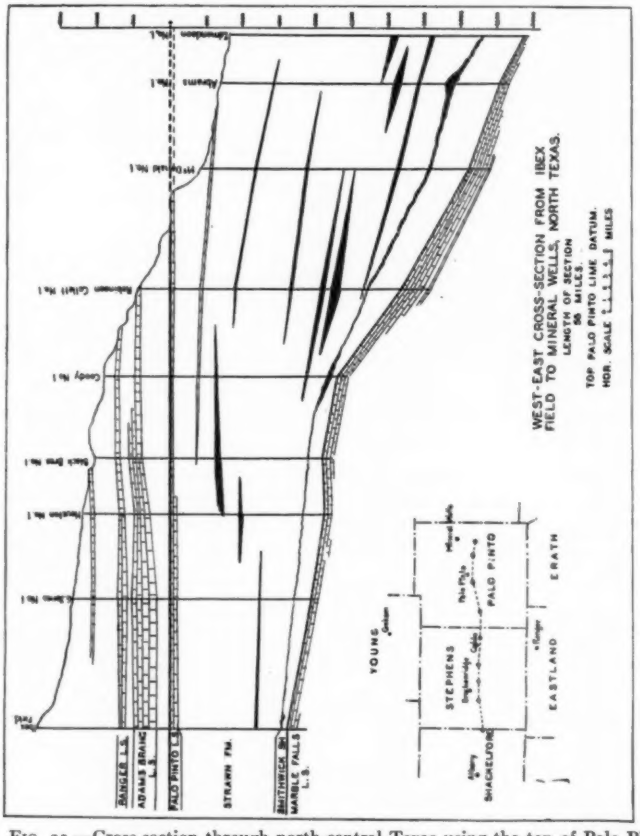

FIG. 11.—Cross-section through north-central Texas using the top of Palo Pinto limestone as a level datum. Based mainly on Plate IX, *Bulletin No. 2132*, University of Texas, by Frederick B. Plummer and Raymond C. Moore. This shows the thinning of the Pennsylvanian toward the west due to the westward overlap of the Strawn formation onto a western land area. It also shows the structure of the Marble Falls limestone relative to the Palo Pinto limestone, or the structure of this area at the time the Palo Pinto was deposited.

the Ibex field in eastern Shackelford County and the Mineral Wells region, 60 miles to the east. In this direction the Strawn thickens from about

1,585 to 4,860 feet, a total of about 3,275 feet, or 55 feet per mile. The rate of thickening is more rapid, however, on the east side of the axis of the arch, which passes through eastern Stephens County. Here the convergence averages 80 feet per mile, in contrast to 25 feet per mile on the west flank of the arch.

The Palo Pinto lime correlates with the Calvin-Oswego formation, and the Smithwick shale–Marble Falls lime correlates with the Wapanucka-Morrow lime of Oklahoma. A common basis of comparison is therefore obtained between Oklahoma and Texas.

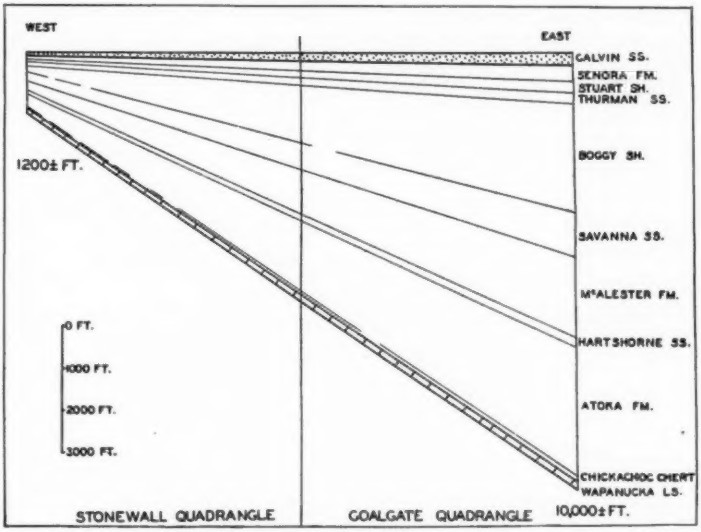

FIG. 12.—Idealized section across Coalgate and Stonewall quadrangles, Oklahoma, showing southeast thickening of Pennsylvanian sediments as measured at outcrop. Thickness is taken from George D. Morgan's report on the Stonewall quadrangle and J. A. Taff's report on the Coalgate quadrangle.

ARDMORE BASIN

From the information available to the writer, the Pennsylvanian section of Jefferson County and the western end of the Ardmore basin is considerably thinner than on the eastern end near Ardmore. Here the interval between the Hoxbar and the Otterville, equivalent to the interval between the Palo Pinto–Oswego and the Marble Falls–Morrow, reaches approximately 10,000 feet.

COALGATE-STONEWALL QUADRANGLE, OKLAHOMA

On the north side of the Arbuckle Mountains the surface sections measured by Taff[1] in the Coalgate Quadrangle and by Morgan[2] in the Stonewall Quadrangle show a marked thickening toward the east. This is

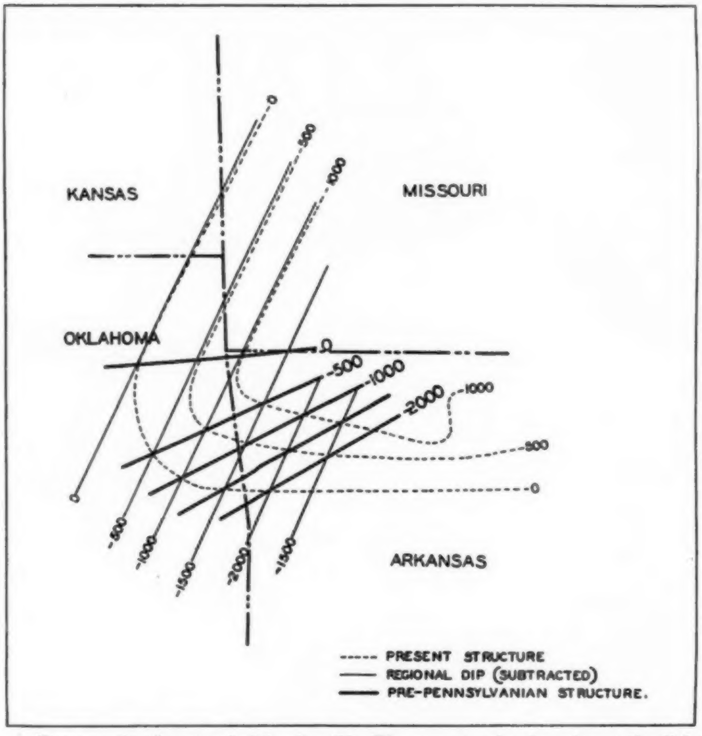

FIG. 13.—Southwest end of Ozark uplift. The present regional northwest dip (light solid lines) is subtracted from the present structure (light dashed lines), resulting in the pre-Oswego lime structure (solid heavy lines) of the top of the Mississippian.

diagrammatically shown in Figure 12, where in 50 miles the section thickens from 1,200 feet to 10,000 feet, or at the average rate of 175 feet per mile. This is attributed by Morgan[3] to westward overlap of the younger formations.

[1] J. A. Taff, "Atoka Folio," *U. S. Geol. Survey, Geol. Atlas No. 79* (1903).

[2] George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bureau of Geology*, Norman, Oklahoma, *Bull. 2* (1924).

[3] *Op. cit.*, p. 19.

EAST-CENTRAL OKLAHOMA

Figures 2, 3 *A* and 3 *B*, 4 *A* and 4 *B*, and 5 show the northwestward convergence through east-central Oklahoma. The Mississippian structure at the end of Calvin-Oswego time, as has been previously pointed out, was a southeast-dipping monocline, flattening toward the west.

OZARK UPLIFT

The present structure of the Ozark uplift, particularly the southwest end, is that of a southwest-pitching fold. The dotted lines in Figure 13 show this in 500-foot contours on the top of the "Mississippi lime." This structure, however, also involves the present regional west-northwest dip extending through Texas, Oklahoma, Kansas, and western Missouri. To reduce it back to the structure of the Mississippian at the time the Oswego lime was deposited, or to reduce it to its natural datum, this regional dip (light solid lines) is subtracted from the present structure. The resultant (solid heavy lines) is a much steeper south-southeast dip passing into a flat area toward the north or northwest flank of the fold.

COMPOSITE CONVERGENCE, TEXAS AND OKLAHOMA

The various local convergences just described have been between essentially the same formations (Fig. 1). In each case they represent a southeast- or east-dipping monocline of the pre-Pennsylvanian formations at the time the Oswego–Calvin–Palo Pinto was being deposited, and a thickening of the intervening formations in this direction. Figure 14 shows this information assembled on one map. The similarity of conditions between the Ozark uplift and the Bend Arch is striking. The breaks in continuity are in each case due to present lack of information.

The writer believes a reasonable interpretation of this information is that in Oswego–Palo Pinto time there was a nearly continuous south- and east-dipping monocline in the basal and pre-Pennsylvanian rocks extending at least from northern Arkansas to central Texas; that later, after the Pennsylvanian and Permian were deposited, the entire section, extending through Texas, Oklahoma, Kansas, and Missouri, was tilted, resulting in the present regional northwest dip of the younger formations and the Bend-Ozark arch in the older beds. The Bend Arch of north Texas and the Ozark uplift of Missouri, together with the intervening area, are, therefore, essentially a part of the same structural feature. This is diagrammatically shown in Figure 15, which shows the Bend-Ozark arch as caused by two opposed regional tiltings.

The Ouachita, Arbuckle, and Wichita folding all started after the southeast monocline had been in existence for a long time, because the folding here involves formations up through the Boggy formation. The

FIG. 14.—Compilation of convergence data of north-central Texas and eastern Oklahoma.

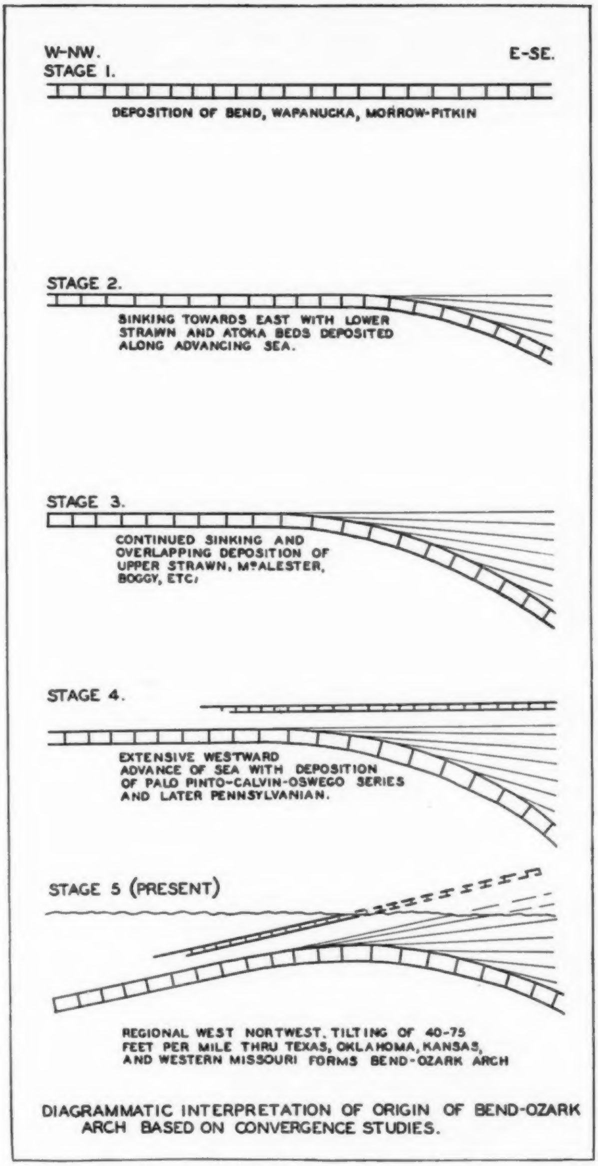

FIG. 15.—Diagram showing progressively the origin of the Bend-Ozark arch, based on convergence studies.

shallow depth to the pre-Cambrian rocks in northern Texas can be readily explained in the same way. In other words, the east-west line of folding through southern Oklahoma is a later development than the southeast-dipping monocline.

Since in each area the northwestward and westward convergence of the Pennsylvanian formations is caused by progressive westward overlap of the younger formations, the different contours in Figure 14 could well represent progressively northwestward advancing shore lines of an ancient Gulf of Mexico. Where the contours are closely spaced, the south and east tilting or sinking of the Mississippian floor was more rapid. When the sea reached the top of the monocline it made a much greater advance, depositing the Oswego lime far into Kansas. As shown in Figure 4 *B*, this latter advance probably started after the Bartlesville sand was deposited.

A feature which may be a coincidence, or may be due to a related origin, is the direction of the Choctaw fault and of the Ouachita folding. It is practically parallel to the direction of the convergence contours. Occurring as it did, after Boggy time, the rapid thickening of the sediments through this area may have had something to do with the direction of relief of pressure and with the origin of the forces involved.

With the sea advancing toward the west and northwest along a front of 700 miles or more, and the younger formations progressively overlapping the older beds in this direction, a reasonable conclusion would be that the source of the early Pennsylvanian sediments was partly or entirely from the west and north.

FUNDAMENTAL CRITERIA FOR OIL OCCURRENCE[1]

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ABSTRACT

Criteria for oil occurrence are considered as being grouped into (*a*) fundamental criteria and (*b*) secondary criteria. This paper pertains mainly to those in the first group. Although geologists once considered that only three or four criteria must be affirmatively answered in order to predict oil occurrence, these have been supplemented from decade to decade, so that no less than eight fundamental criteria are now enumerated, all of which must be answered affirmatively if a district or locality is to be considered favorable for oil. These criteria are discussed in their various aspects and interrelations. In addition to a discussion of the fundamental criteria, a list of secondary criteria is given with the intention of making it the subject of an independent paper at a later date.

SCOPE OF PAPER

This title is made to read "Fundamental Criteria of Oil *Occurrence*" after due deliberation. So much has been written on the "occurrence," "distribution," and "accumulation" of petroleum deposits that geologists have sometimes confused the respective terms. So far as possible, the use of the word "accumulation" has been avoided here, and, when used, it refers to the *process* of accumulation, whereas "distribution" denotes the *place* of the oil inside a field. "Occurrence," on the contrary, is here used to express the actuality of *existence* of the deposits.

This paper is concerned primarily with proved fields of commercial value, and not with minute or sporadic oil deposits that may occur in rocks of many ages, structures, and various modes of origin. In a consideration of the subject it seems desirable, however, to include certain semicommercial fields or those of unproved value, for to omit them would be to neglect some of the interesting or important phases of occurrence.

In the past most of the discussions of the oil prospects of a region have been prefaced by a more or less extended outline of conditions considered necessary to oil occurrence. Long ago the essentials were stated as (*a*) a porous reservoir to hold the oil, (*b*) an impervious cover to prevent its escape, and (*c*) some form of geologic structure suitable for its concentra-

[1] Read before the Association, Tulsa meeting, March 26, 1927. Manuscript received by the editor, April 21, 1927.

[2] Consulting geologist and petroleum engineer, 50 Church Street, New York City.

tion in commercial quantity in a pool. These conditions have generally been considered fundamental, and they may still be so considered; but the progress of our science has been so rapid that the previously recognized three fundamental criteria have been added to from decade to decade, and we are no longer satisfied with those once enumerated. Instead, there is an array of fundamental and secondary factors in oil occurrence that was little thought of a few years ago.

The purpose of this paper is to set forth the criteria recognized at this writing, with the hope that discussion and later papers will elaborate the subject. A statement of criteria may tend to counteract the common tendency to overemphasize the importance of structure in connection with any particular province or investigation.

As the paper may be considered a review of the present stage of oil geology, no apology is offered for including in it some factors of an elementary character which are commonly accepted by the profession. The paper does not, however, include methods of work or phenomena of observation. All facilities, instruments, and modes of observation or reasoning are, for the purpose of the paper, considered as constituting *methods* of work, rather than *criteria*.

Acknowledgment is here made to all professional colleagues of the writer who have been the source of information or ideas or who have contributed in the past to the progress of oil geology.

FUNDAMENTAL CRITERIA

For convenience of discussion, the geologic factors involved in oil occurrence are divided into *fundamental* criteria, or those absolutely necessary in a search for oil in an untested region, and *secondary* criteria, or those which need not be considered but may be important in a final analysis of the situation.

The *fundamental* criteria, which are the subject of this paper, are mentioned in Table I in the order of their logical consideration.

IMPORTANCE OF PRACTICAL UNANIMITY

For purposes of this discussion a desirable axiom may be that an oil field cannot be safely predicated on the basis of one or two geologic factors alone, but that the many criteria must be given their proper weight. David White has already shown[1] that "geologists do well to walk humbly and punctiliously to admit that the geologic principles controlling the

[1] "Genetic Problems Affecting Search for New Oil Regions," *Min. and Met.*, No. 158, Sec. 21 (February, 1920), pp. 20.

distribution of oil and gas have as yet been discovered only in part, and that which remains yet to be learned is probably vastly more than what is already known." Therefore, even after due consideration of all known factors, a field cannot be successfully located simply because a majority or nearly all the questions propounded as working hypotheses have been answered affirmatively. At least, a negative answer on a locality must not prevail if oil is to be safely predicted.

TABLE I

FUNDAMENTAL CRITERIA FOR OIL OCCURRENCE

1. Do "surface indications" (seepages, etc.) exist?
2. Are the rocks of sedimentary origin?
3. Is the age of the strata (in part at least) similar to that prevailing in some known oil or gas field?
4. Does a possible source of origin exist? If this be not apparent, may it nevertheless be present?
5. Do porous beds or reservoirs exist in which oil may be held in commercial quantity?
6. If so, does sufficient "cover" exist above those beds to prevent oil or gas from escaping to the surface and from being lost?
7. Are the strata so slightly metamorphosed by heat or pressure that the oil has presumably not been driven away?
8. Does geologic "structure" exist suitable for concentrating oil or gas in commercial quantity?
9. Are the hydrostatic conditions such as may not prohibit the accumulation of oil in pools?

Although the writer will not go so far as to assert that drilling ought never to be undertaken in the absence of final affirmative answers to all the fundamental criteria, it seems safe to assert that test wells *can* be safely drilled if every question be answered favorably. If some criteria be answered favorably and the answer to others be unknown, the venture may still constitute a "good gamble"; nevertheless, as a rule, if all but two criteria be answered negatively, the prospects can be considered unfavorable. In fact, the writer has in mind only one fundamental criterion, namely, presence or absence of genuine oil seepages or "surface indications," that can be answered in the negative and a reasonable prospect still remain of finding oil in commercial quantity. In other words, if the strata be of an age in which oil or gas is elsewhere unknown, or if their character be such that no known source of origin can exist, or if no porous reservoirs appear to exist with an overlying impervious cover, or if local geologic "structure" be nowhere suitable for concentrating oil in

commercial quantity—if any of these defects exist, a field is probably not present.

It may be also argued by some persons that the finding of a source of origin is not essential, since geologists differ as to the origin of oil, and this phase of the question of unanimity is discussed in the portion of this paper entitled "Source of Origin."

SURFACE INDICATIONS

Classification of "surface indications."—From a world-wide viewpoint, the commonest evidences of the existence of oil may be "surface indications." Although not most important from a geologic point of view, these are so obvious in some oil-bearing countries that in popular opinion they constitute the principal, and sometimes the only, indication of the presence of oil.

Geologists naturally recognize the fact that "surface indications" are not essential, since many producing fields evince no "surface indications." This may be because the strata are so thick, so unbroken, or so impervious that no escape of oil, gas, or any naturally derived product has taken place.

The principal so-called "surface indications" are classified in Table II, but not all of them are universally accepted by us as true indications.

TABLE II

SURFACE INDICATIONS OF OIL OCCURRENCE

1. Oil seepages or "oil springs"
2. Natural gas seepages or "gas springs"
3. Outcrops of sandstones or limestones impregnated with petroleum or bitumen
4. Bituminous dikes
5. Mud volcanoes
6. Burnt clays
7. Occurrence of salt water, saliferous beds or massive salt deposits
8. Occurrence of sulphur, hydrogen sulphide, or gypsum

Any one of the named "indications" may have some association with oil, but oil may occur at a great distance from the point where the indication reaches the surface. Since a formation from which seepages are seen to emerge may descend at such an angle that the structurally favorable locality lies miles from the exposed outcrop, it is certainly a wrong policy to drill on or near seepages unless evidence exists that the main oil or gas deposit lies directly below the particular point. The relative values of the different "surface indications" are now considered.

1. *Oil seepages or "oil springs."*—In 1915 the classification of seepages, or oil springs, stated in Table III was proposed by DeGolyer.[1]

Seepages commonly emerge either (1) where the outcrop of an oil-bearing bed or rock reaches the surface, or (2) where a crevice or fault enables oil to rise to the surface. Under the first condition the oil may be manifested as a small film on rivers or lakes, as was true in some Pennsylvania, Ohio, and West Virginia fields in the early days of their discovery, and as has been noticed by geologists in nearly every country,

TABLE III

CLASSIFICATION OF SEEPAGES

I. Seepages associated with igneous intrusions
   a) at contact zones of volcanic plugs and sedimentary rocks,
   b) at contact zones of dikes and sedimentary rocks,
   c) through cracks and fissures in the igneous rock itself,
   d) as intrusions in the igneous rocks, and
   e) from metamorphosed rock above an intrusion which does not outcrop.

II. Seepages not associated with intrusions
   a) at crest of domes or anticlines,
   b) along marked fault or fissure planes,
   c) from steeply-dipping strata, and
   d) isolated occurrences or uncertain relations.

in some places even where commercial oil does not exist. Small films may come from organic matter buried in Quaternary or earlier deposits, as in New Jersey and Georgia, or they may be the manifestation of non-commercial oil contained in sandstones with little shale capping, as in northern Shensi Province, China. Hence, if the seepages be of this mild type, the other fundamental criteria must be even more carefully considered than if no seepage be apparent, for a natural tendency seems to exist to place too great stress on any seepage as an argument for oil occurrence. Naturally, it is essential to ascertain whether or not a reported seepage is genuine.

As opposed to minute oil films, oil emerges from the earth in large volume in Mexico, Trinidad, Venezuela, Colombia, New Zealand, Persia, Russia, California, and some other countries. In the United States the question is repeatedly asked why seepages so seldom appear in some productive fields, and the answers commonly given are: that the beds are so slightly tilted as to have remained unbroken, or so little fissured that oil could not reach the surface. Where productive strata of Carboniferous

[1] DeGolyer, *Econ. Geol.*, Vol. 10 (1915), p. 654.

and earlier ages actually outcrop in a distinct locality, the oil may have disappeared from that point owing to metamorphism, erosion, evaporation, or other factors. Obviously, oil of paraffin base less commonly leaves traces on the surface than that of asphalt base.

2. *Natural gas seepages, or "gas springs."*—In some fields bubbles of gas rise in minute quantities to the surface of stream or lake water. In other parts of the world gas in large quantities has actually been burning for thousands of years. Genuine natural gas springs, while not constituting actual proof of the existence of petroleum, show that conditions are potentially favorable, for where the gas is found we may expect oil also within the lateral range of the same formations. If the gas be "wet," that is, a carrier of gasoline, the probability of the occurrence of oil in proximity to it is increased, but the importance of having "wet" gas as opposed to "dry" gas as a sub-criterion is sometimes exaggerated. An elementary but necessary factor is of course the distinction between true natural gas and "marsh gas," and the distinction, if it is to be of value for purposes of petroleum prediction, must be a critical one.

In addition to the differences in size of seepages and their continuity in time and space, natural gas and "marsh gas" are not generally identical in composition. Pure "marsh gas" is methane (CH_4), such as forms the basis of most natural gases; but "marsh gas" is seldom, if ever, found in this pure form, and, more commonly, it has a composition roughly represented by Sample No. 3 in Table IV.

A classification of gases is of interest, and this can be conveniently given by means of Table IV. The presence of ethane (C_2H_6) up to 20 per cent of a gas does not assure us with absolute certainty that an oil field exists in the vicinity, but ethane occurrence is considered a more favorable sign than if the gas is pure methane. The existence of unsaturated hydrocarbons (olefines, etc.) in some gases is decidedly favorable to the existence of oil.

Since so many different types of gas exist throughout the world, it is well to consider true "natural gases" as opposed to those of other kinds. In the following table of representative types of gas, the first two are "*natural* gases," such as are commonly associated with petroleum.

3. *Outcrops of sands, sandstones, or limestones impregnated with tar or bitumen.*—Outcrops of formations impregnated with tar or bitumen are not common, but they exist in some parts of the world. Perhaps the best-known evidences of this kind are the "tar sands" of the Athabasca and other rivers in northern Alberta. As opposed to these fine examples derived from asphaltic-base oils, the outcrop of a paraffin-base "oil sand"

is in few places visibly petroliferous, because of the oxidation and evaporation which are continually taking place; but the outcrops of asphalt-base oils are in many places distinctly bituminous or show a brownish residue. Some compact limestones contain small globules of oil, or if oil be present in the vicinity it can sometimes be detected by the odor after striking the outcrop with a hammer. Testing by the chloroform and laboratory methods frequently gives indications.

4. *Bituminous dikes.*—The relationship of dikes of asphalt and other bitumens to oil occurrence is not so apparent, since these substances are

TABLE IV

COMPARATIVE TABLE OF DIFFERENT KINDS OF GASES*

Kind of Gas	1	2	3	4	5
Methane (CH_4)	66.90	83.40	76.61	0.17	....
Ethane (C_2H_6)	10.00	10.31	....	....	....
Unsaturated hydrocarbons	2.25	0.61	....	....	....
Carbon dioxide (CO_2)	1.05	....	5.36	72.63	1.01
Carbon monoxide (CO)	....	....	....	....	Nil
Nitrogen	17.05	5.19	18.03	23.91	78.90
Oxygen	2.75	....	....	....	20.09
Hydrogen	....	0.33	....	....	....
Hydrogen sulphide (H_2S)	....	....	....	3.29	....
Helium	....	0.16	....	....	....
Sulphur dioxide (SO_2)	....	....	....	....	....
Totals (percentage)	100.00	100.00	100.00	100.00	100.00

*1. Hylands natural gas springs, Waimata Valley, Cook County, New Zealand (J.B. Maclaurin, *52d Ann. Rept., Dominion Lab. of New Zealand*, 1919, p. 47).

2. Natural gas from Blackwell oil field, Kay County, Oklahoma, Cady & McFarland, analysts (*Jour. Amer. Chem. Soc.*, Vol. 29, p. 1530).

3. "Marsh gas" from Marburg Botanical Gardens, Germany (after Maumeme).

4. Gas from hot mineral spring at Nenndorf (H. P. Westcott, *Handbook of Natural Gas*, Erie, 1915, p. 105).

5. Volcanic gas from fumarole in lava stream of 1845, Iceland (Robert Bunsen, analyst).

frequently quite solid. The albertite mines of New Brunswick, grahamite dikes of Ritchie mines, West Virginia, and bituminous dikes of Argentine, Oklahoma, and elsewhere are noteworthy examples. Oil may be present in such dikes in the form of "kerogen," yet its presence proves that the conditions are petroliferous.

5. *Mud volcanoes.*—The question of whether mud volcanoes constitute an evidence of the existence of oil has been frequently debated, and perhaps has not yet been adequately answered, for the phenomena occur in parts of the world where oil is at present unknown. Mud volcanoes do, however, constitute an evidence of the existence of *gas*, and this, if it be "wet" *natural* gas, may lead to inference that oil is associated with it.

6. *Burnt clays.*—In a few places in the world beds of clay shale as much as 10 feet thick have been naturally baked at depth by the combustion of bituminous material in, or associated with, them. Clays are, however, also baked by the combustion of coal and peat beds, so that the cause of burning should be ascertained in any investigation of possible oil occurrence.

7. *Presence of salt water, saliferous beds, or massive salt deposits.*—Salt is generally associated with oil, either in the form of crystalline masses, salt water, or saliferous strata. Water which accompanies petroleum may be more saline than that normally present in sedimentary rocks. On the other hand, extensive masses of salt and thick beds of saliferous strata exist in many places unassociated with commercial oil, as in Germany, Hungary, Ontario, New York, Kansas, and Ohio. Consequently, theories for the origin of oil often ignore a relationship with salt as a factor in the process, assuming that brine, where found in an oil field, is a normal constituent of deeply buried formations of marine origin. Perhaps the common idea that salt and oil are necessarily associated is derived in part from the fact that the latter was originally discovered in Pennsylvania and West Virginia during the search for brine, which was at one time obtained from wells in those states. The association of oil with salt domes may be due merely to a concentration of oil against the salt mass as a suitable structure. In West Virginia and in the Clinton sand of central Ohio salt water is seldom found associated with oil. Salt is therefore not properly a criterion for oil occurrence, but the known occurrence of salt in association with oil is worthy of more study.

8. *Occurrence of sulphur, hydrogen sulphide, or gypsum.*—In a few places in Louisiana and Texas oil is associated with sulphur, and gypsum is one of the common minerals pointed to by many persons to prove a relationship between oil and sulphur. Some persons have supposed that the occurrence of hydrogen sulphide is favorable to that of petroleum, but there seems to be no probability of such a connection.

Summary.—Summarizing the foregoing comments, it must be acknowledged that "surface indications" are not essential to the occurrence of an oil field, since in some fields there is an entire absence of such indications. Where oil seepages or other accepted indications exist, however, they indicate oil below the surface in greater or less quantity. Similarly, since asphaltic deposits are derived from oil, petroleum has once existed in localities where asphaltic deposits exist, and we must determine on the basis of other fundamental criteria whether or not the conditions are such that oil may still be expected in quantity. Where natural gas exists with-

out associated oil, there is no positive evidence of the latter; but since gas and oil are believed to be derived from a common source, we may expect to find evidences of oil somewhere in the same general region.[1]

SEDIMENTARY ROCKS AS CRITERIA

It seems unnecessary, in a paper designed for this Association, to discuss the necessity of finding rock of sedimentary origin before proceeding further in a search for oil. Therefore, this criterion is merely included here for the sake of completeness. It will do no harm to add that, if the surface be composed of extrusive igneous rocks having sedimentary beds beneath them, the criterion may be considered as satisfactorily answered. The writer may also remark that dikes do not inherently prevent oil occurrence.

AGE OF THE STRATA

Although oil occurs in greater or less quantity in formations of nearly all geologic ages, important fields have been found only in the Ordovician, Silurian, Devonian, Carboniferous, Cretaceous, and Tertiary systems, and Tertiary rocks are believed to yield more than 50 per cent of the world's production. Only small deposits of oil have been found in Cambrian strata. Consequently, if the strata be of pre-Cambrian or post-Tertiary age, they may logically be surveyed with suspicion, even if the other fundamental conditions be found satisfactory. Where oil occurs in quantity in post-Tertiary strata it has generally escaped from older beds. The principal ages of oil-bearing strata are condensed into Table V, but they are not all commercially proved at the present time.

The writer has been criticized in some quarters for ruling out areas as non-oil-bearing, which are of pre-Cambrian age. Such eliminations may not be safe, but they accord with experience and logic.

SOURCE OF ORIGIN

A discussion of the pertinence of source of origin in this connection is approached with hesitation for several reasons. In the first place, origin involves theoretical considerations which, as such, may not be entirely deserving of inclusion among criteria which are to be accepted as proved facts. In the second place, any discussion of origin is likely to lead into extended controversy, which is not the purpose of this paper and which the writer is not prepared to undertake at present.

[1] Since this paper was written the writer has received a copy of A. Beeby Thompson's "The Significance of Surface Oil Indications" *Jour. Inst. Petrol. Technologists*, Vol. 12, No. 59, 1926, pp. 603–22, which constitutes an important addition to the literature.

The inclusion of source of origin among the criteria seems important from one standpoint alone, that is, the presence or absence of some recognized possible source in any locality may be considered as constituting a measure of the relative probability of the existence of oil there in contradistinction to other areas. Whether we consider that oil can be of sedimentary, chemical, or bio-chemical origin, or, if, on the contrary, we adhere firmly to the organic theory as generally accepted, we must admit

TABLE V

STRATIGRAPHIC OCCURRENCE OF OIL AND GAS

Era	System	Country
Cenozoic	Quaternary	United States
	Tertiary	United States, Mexico, Trinidad, Russia, Rumania, Poland, Ukrainia, East Indies, Peru, Japan, Italy, Colombia, Venezuela, Persia, Iraq, New Zealand, Argentine, France, Egypt, India, Japan, and Formosa
Mesozoic	Cretaceous	United States, Canada, Mexico, Persia, Iraq, Poland, Ukrainia, Colombia, Venezuela, Ecuador, Argentine, New Zealand
	Jurassic	United States, Germany, Argentine
	Triassic	United States
Paleozoic	Carboniferous	United States, Canada, China, England
	Devonian	United States, Canada
	Silurian	United States, Canada
	Ordovician	United States, Canada
	Cambrian	United States, Canada

that any possible source for oil, even if obscure and doubtful, might constitute a criterion of some degree. Where all evidences of source rocks are absent we can avoid giving weight to the probability of oil, as opposed to numberless cases where possible sources of one kind or another have been observed.

Thus we must, as shown by White,[1] consider carefully the "sufficiency of carbonaceous detritus and residues." Since the organic theory is accepted by most geologists in some form, the pertinence of finding organic remains is axiomatic. We may differ as to the origin or as to what constitutes an organic source, but we need probably hesitate no longer to accept the discovery of an organic source in any prospective field as a

[1] *Loc. cit.*

favorable criterion. If indications exist that organic matter has once lived in the rocks, they need not be noticeably carbonaceous, petroliferous, or organic. Obviously, since oil may have migrated, a source may be near to, or far above or below, any producing "sand."

A source of origin may not always be provable; nevertheless we should ascertain that conditions do not prohibit the existence of some source. For instance, if the locality consist entirely of non-extrusive igneous rocks or if the strata be exclusively quartz sandstone from the land surface down to the underlying igneous or metamorphic basement, most of us would accept the evidence as prohibitive to oil occurrence.

Many subsidiary problems arise in connection with the acceptance of the existence of a source of origin, but these need not be discussed here. For instance, an important problem is whether oil has been of marine origin or of fresh-water origin or both. Again, at the present stage of our science we need not necessarily exclude oil shales from the category of source rocks, but the definite acceptance of oil shales would be debated by many geologists.

With these few unsatisfactory remarks on the subject of origin, we will pass to the various more positive criteria.

RESERVOIR ROCKS

It is generally conceded that an oil- or gas-bearing rock must be porous, though there are some exceptions to this statement. The porous stratum generally consists of sand, sandstone, porous or cavernous limestone, or dolomite. Examples of commercial deposits of fluid oil or gas in shale and joint cracks are so limited that they appear to be exceptions and not modifications of the rule, and are not given place in this paper. The presence of oil or gas in limestone may be due to the natural porosity of the rock, to simple solution, or to changes consequent to the formation of dolomite. Thus the exact area of occurrence may be limited, not by detailed structure of the porous stratum, but by its internal characteristics.

An oil reservoir may terminate by lensing out, by the cementing of the "sand," by faulting, by intrusion of igneous rocks, or by the sealing action of paraffin or asphalt. Thus, in case of sandstone, the locality of occurrence is due not alone to structure, but also to continuity and porosity of the stratum, and we therefore eliminate a discussion of the *distribution* of oil deposits from the scope of this paper.

In studying an outcrop of sandstone with reference to its probable effectiveness as an oil container, it is important to bear in mind the thickness, percentage of porosity, and its continuity. The effective porosity is

naturally dependent on the size, arrangement, and shape of the individual grains and the amount of cementing matter between them. Many of the samples tested at different times for porosity have been derived from outcrops rather than from well cores, and may not be fairly representative. They show porosities ranging from 0.108 to 0.519 in granite, 0.53 to 13.36 in limestone, and 4.81 to 28.28 per cent in sandstone.[1]

In considering the suitability of a deeply buried sand as an oil reservoir it is well to bear in mind the probable relative area of deep sand pools as opposed to the respective overlying shallow sands, but this sub-criterion may be considered a factor of distribution rather than of occurrence.

In dolomites or cavernous limestones the spaces are generally so irregular that no porosity determination is of value, except where their cavernous nature is supplemented by oölitic or granular structure.

Some factors of porosity are considered by Wroblewski.[2] The terms sand, sandstone, sand body, reservoir, pay, field, and pool are generally loosely used, and care should be taken to avoid confusion. However, the term "sand" is used for the pay stratum so widely that there is probably no chance of general modification in its use.

A complete discussion of porosity should be undertaken from separate viewpoints as pertaining to (*a*) sands, (*b*) sandstone, (*c*) compact limestones, (*d*) cavernous limestones, (*e*) dolomites, and (*f*) oölitic beds; but certain statements may be advanced as generally applicable to all of those types of strata.

THE COVER ROCKS

Although the bed of impervious rock immediately overlying an oil "sand" may be termed the "cap rock," this factor, like the porosity variations from place to place in a "sand," is considered as belonging to the subject of *distribution* of oil or gas within a recognized field, and not to the broad question of the *possibility* of its occurrence in the area; hence, it is not considered a criterion of *occurrence*. The class of cover rocks that would ordinarily be considered suitable for holding a commercial field within a porous "sand" and preventing the escape of oil or gas are thick deposits of shale, clay, or compact limestone, generally hundreds or thousands of feet in thickness, and the presence of such deposits in any region may be considered a satisfactory answer to criterion No. 6 (Table I).

[1] E. B. Buckley, *Building and Ornamental Stones of Wisconsin.*

[2] Adam Wroblewski, "Sand Structure and Oil Production," *Oil and Gas Journal*, April 13, 1922, 6 figs.

METAMORPHISM

The word "metamorphism" is broadly used by geologists to denote all internal changes in character that rocks undergo after their original deposition or formation. Metamorphism is of great interest to petroleum geologists because it demarks immense regions of the earth where oil does not exist in commercial amounts.

We are in the habit of considering the question of metamorphism in a twofold sense. First, are the rocks *destructively* metamorphosed, or to such an extent that they *can* hold no oil? If so, they are generally hardened, veined, mineralized, or noticeably altered so that extreme metamorphism is apparent, even to a novice. Whatever may be the origin of petroleum, we know from experience that it is never discovered commercially in igneous rocks, except under very rare and minor conditions constituting a "freak" occurrence. Moreover, oil is not found in the ancient metamorphic rocks which are greatly distorted by folding over wide areas and in which evidences of internal metamorphism are visibly due to heat or pressure. Thus we may at the outset exclude from consideration rocks of the igneous and intensely metamorphic groups.

Secondly, if rocks are not destructively metamorphosed or altered to such a considerable extent, have changes taken place of a more moderate type such as might be indicated by an adverse carbon ratio in coals or shales or determined by the change in amount or quality of certain waters, or of water of crystallization, or by microscopic or macroscopic mineralization?

Judging by some opinions expressed to the writer, it may be necessary to add a third sub-criterion in the consideration of metamorphism. Whereas the first and second factors named are those of *too great* metamorphism to permit the present occurrence of oil or gas, it may be necessary to consider whether, on the contrary, there may have been *too little* metamorphism to have formed or accumulated oil or gas. We sometimes consider that Pleistocene beds of slight folding have this defect. May such a condition not also prevail in Tertiary beds? So far as known to the writer, this question has been answered in the abstract, but not satisfactorily with reference to any particular region.

The last-mentioned doubt involves much theory, which it is not proposed to enter here. The relation of metamorphism to pressure and heat is seriously involved, and brings us again to the question of origin, which has been already passed.

Until within a few years, geologists were unable to explain the absence of oil near some of the principal mountain systems of the world, and no

guide had been discovered by which they could delimit the unmetamorphosed regions where oil may be expected from the regions of metamorphism where it evidently does not exist. In 1915, however, White's paper[1] appeared, showing that in regions of Carboniferous coal beds the ratio of fixed carbon decreases in a regular manner from the anthracite regions or those of semi-bituminous coals to the softer bituminous coal regions, and that in going from soft to harder coal regions this ratio passes a line beyond which no commercial oil fields may be expected.

The discovery of wells producing naphtha or "white oil" in regions of metamorphism beyond the critical carbon ratio might seem to controvert the value of this criterion; yet no large fields have been proved beyond the critical ratio, and it is doubtful if any such fields have "paid out."

The value of the test by *isovols* was subsequently checked in papers of Fuller,[2] Semmes,[3] and others. Many geologists are inclined to doubt the efficacy of carbon ratios; yet in general where carbon ratios have been studied we find that oil fields of commercial importance seldom exist beyond the 63 per cent line of fixed carbon, and that commercial gas fields seldom exist beyond the 75 per cent line. Carbon ratios also doubtless change with increasing depth in any locality, but this subject has been less studied than the ratios in surface rocks.

We can hardly doubt that the carbon ratio of a locality or formation is of some value as a criterion, and subsequent work will tell the full story of its utility.

STRUCTURAL CRITERIA

The last great class of criteria considered here comprises those of a structural nature. In the early days of oil geology, structure was the principal and almost the only factor studied, after elimination of the large areas of igneous rocks and those of obviously intense metamorphism. With advance of the profession the factors discovered in preceding paragraphs have been recognized and their importance appreciated, and structural geology, although as important as ever, has had to take its place as the final fundamental criterion, with one exception.

[1] David White, "Some Relations in Origin between Coal and Petroleum," *Jour. Wash. Acad. Sci.*, Vol. 5 (1915), No. 6, pp. 189–212; *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 727–34.

[2] M. L. Fuller, "Relation of Oil to Carbon Ratios of Pennsylvanian Coals in North Texas," *Econ. Geol.*, Vol. 14 (1919), No. 7, pp. 536–42; "Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relation to Petroleum," *Econ. Geol.*, Vol. 15 (1920), No. 3, pp. 225–35.

[3] D. R. Semmes, *Mining and Metallurgy*, No. 159, March, 1920

We need here not distinguish between deformational structure and that due to thickening or thinning of a sandstone along its roof or to subsidence of sediments during consolidation over a previously existing

TABLE VI

CLASSIFICATION OF OIL AND GAS STRUCTURES

I. Aclinal or sub-aclinal structure
II. Anticlinal and synclinal structures
  a) Strong anticlines standing alone
  b) Well-defined alternating anticlines and synclines
  c) Broad geanticlinal folds
  d) Overturned folds
  e) Lenticular nature of the sands
III. Monoclinal structure
  a) Monoclinal noses
  b) Monoclinal ravines
  c) Structural terraces or "arrested anticlines"
  d) Lenticular nature of the sands
IV. Quaquaversal structures, or "domes"
  a) Anticlinal bulges or "cross-anticlines"
  b) Monoclinal bulges
  c) Closed saline domes
  d) Quaquaversal structure caused by volcanic plugs
  e) Perforated saline domes
V. Contact of sedimentary and igneous rocks
  a) Contact of sedimentaries with volcanic plugs
  b) Contact of sedimentaries with dikes
  c) Contact of sedimentaries with intrusive beds
  d) Contact of sedimentaries with other igneous rocks
VI. Strata dipping unconformably away from an old shoreline
VII. Crevices of igneous rocks
VIII. Crevices of sedimentary rocks
IX. Faults*
  a) Upthrow side
  b) Downthrow side
  c) Overthrusts
X. Oil deposits sealed by bituminous deposits

* Distinction should be made between (*a*) transverse faults like those in the Salt Creek field, (*b*) longitudinal *sealed* faults, and (*c*) shear faults like those of central Oklahoma.

land mass. Any one of these types, when causing suitable structure, and with the presence of the other fundamental criteria, may permit the occurrence of oil.

In 1910 the structural classification[1] was proposed, and it was published in full in 1917.[2] As a record of the known subcriteria under "Structure," this classification is reprinted in Table VI. Its object is to describe the different types of oil and gas accumulations or occurrences by grouping them into classes, each division of which constitutes a special type of structure.

Unfortunately, this classification has been considered by many persons as an argument in favor of the "anticlinal theory," whereas it was intended, not as an argument for any theory, but merely as a statement of the type of structures on which oil occurs and the relations of oil to such structures, whether they be anticlinal, synclinal, monoclinal, or quaquaversal.

Many geologists have contributed in supplying new types of oil occurrences from time to time. The chief alternative classification known to the writer was proposed by Johnson and Huntley and was termed by them "a classification of the attitude of geological surfaces."[3] The prime divisions of their classification were given as aclines, homoclines, domes, level-axis anticlines, plunging-axis anticlines, noses, and synclines.

Structural criteria may be grouped briefly into several essentials, generally given careful consideration by a geologist, but which, in view of their nature, do not permit enumeration as part of any structural classification. Or, if they could be enumerated, they would not partake of the nature of sub-classes or sub-types of structure, but as qualities due to various structural types. Some of these conditions are: size, height, breadth, flatness, amount of closure or its absence, and the size of the "collecting area" (occasionally termed in geologic parlance the "drainage area"). It appears that none of these conditions has any definite effect on the existence or amount of production. Yet most geologists may be inclined to express themselves on the merits of the following statements as applicable after the other criteria have been found satisfactory:

1. A dome or anticline of *small* size will now seldom be avoided by most oil geologists. On the other hand, a dome of *great* proportions has been in many cases found too large to concentrate oil in commercial quantities except in superimposed "pimples."

2. A high dome or anticline is presumed to be advantageous; but it

[1] F. G. Clapp, *Proc. Eng. Soc. W. Pa.*, Vol. 26 (1910), No. 4, pp. 87–120; *Econ. Geol.*, Vol. 5 (1910), No. 6, pp. 503–21.

[2] ———, "Revision of the Structural Classification of Petroleum and Natural Gas Fields," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 533–602, 20 figs.

[3] Roswell H. Johnson and L. G. Huntley, *Principles of Oil and Gas Production* (New York, 1916), pp. 63–78.

may be *so* high as to have lost the oil or gas from its crest through metamorphism or erosional leakage.

3. Some geologists have considered a *broad* anticline as favorable for gas and a *narrow* one for oil; but these hypotheses can hardly be said to be more than of very general application even if true at all.

4. In moderately dry sands a flat structural crest has generally trapped more oil than a sharp one. In water-saturated sands little effect may have ensued from differences of flatness.

5. Where a sand is absolutely dry, the oil is generally in the *synclines*.

6. Height of "closure" may mean much or little. However, in areas of great hydrostatic pressure the oil may have been pushed out of a structure having slight vertical closure, but held in one of considerable closure.

7. The size of the "collecting area" or "gathering area" is unquestionably important. Where this area is small, a relatively *minor amount* of oil is generally collected from it on the favorable structure, whatever the cause of the migration may be. The size of the "collecting area" may be the most important of the modifying influences under structure.

HYDROSTATIC CRITERIA

If this were a paper on oil *accumulation*, the importance of moving underground water as a primary cause of migration would be obvious. This theory has been discussed by Rich,[1] but the subject of oil *occurrence* only necessitates its discussion in so far as water affects the *place* of collection or the occurrence of the oil. For present purposes it is not necessary to determine whether oil is concentrated in a structure under conditions explained by the "anticlinal theory," by the "structural theory," by buoyancy of oil on water, or by the relative specific gravities. What does concern us is the existence or non-existence of (*a*) water at a level which has permitted oil to reach its equilibrium on a structure, or (*b*) currents of water strong enough to have forced oil out of a structure. In other words, the hydrostatic conditions that would be considered prohibitive to the occurrence of oil on structural "highs" would be (*a*) absence of water and (*b*) dangerously great pressure of circulating water (taking into consideration the amount of closure, if any, of structures from which oil might be driven by this pressure).

Since we have not discussed the merits of the "anticlinal theory" under the heading of "structure," we need not touch here on the "hydraulic theory."[2]

[1] John L. Rich, *Econ. Geol.*, Vol. 16 (1921), No. 6, pp. 347–71.

[2] Simplified by John L. Rich, "Further Notes on the Hydraulic Theory of Oil Migration and Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 213–25.

The removal of oil or gas accumulations by the action of moving water has been called "flushing." This is "to be expected where altered physiographic conditions cause a change from slow to rapid water circulation." In the San Juan Basin of New Mexico and many basins of Wyoming and southern Montana the structures near the mountains are full of water which has flushed out the oil, and wells drilled on them thus yield artesian water instead of oil. The importance of water in the migration of oil was discussed by Munn[1] many years ago.

SECONDARY GEOLOGIC CRITERIA

The criteria discussed previously in this paper are classified as "fundamental criteria." Assuming now that a possible source of origin be known, that seepages exist, that the ages of certain existing strata are identical with those in some known field, that porous sandstones or limestones or other suitable containers underlie the region, that they are overlain by satisfactory impervious cover, that suitable conditions of non-metamorphism have been proved or inferred, and that correct types of local geologic structure exist, still we may be obliged to report adversely on a region on account of any one of several factors which may conveniently be termed "secondary criteria." In other words, *reconnaissance* or detailed studies may have resulted in the discovery of unfavorable factors in some one or more than one of the following circumstances in addition to the so-called *fundamental* criteria:

1. Faults may exist. These may or may not be favorable to oil or gas occurrence, according to their age, magnitude, position, cause, or type.
2. Crevices and fractures may exist and may be favorable or unfavorable.
3. Favorable porous beds, though present, may lie at such great depth that we must inquire whether or not they can economically be reached by drilling.
4. Although porous beds be present, they may lie on the surface, so that a certain amount of the oil or gas may have escaped.
5. "Sands," though present, may be of insufficient porosity to hold oil or gas in quality, or they may be too fine-grained or dense to yield fluids readily by flowing or pumping.
6. The deposits may be not of near-shore deposition, and one must inquire the bearing of this stratigraphic type on oil occurrence.
7. On the basis of drilling, certain beach, bar, spit, or river channel

[1] M. J. Munn, "The Anticlinal and Hydraulic Theories of Oil and Gas Accumulation," *Econ. Geol.*, Vol. 4 (1909), pp. 509–29, and other papers.

conditions may have been found to exist in the "sands." In other words, is the lensing of sands sufficiently considered?

8. The beds may stand vertically or approximately so, in which case the local structures may be so strong, so superficial or so "open" as to raise the question whether they can hold oil or gas.

9. If oil be present, gas may not accompany it; under which condition no natural means may exist to force oil into wells from surrounding portions of a productive stratum, rendering recovery expensive or impossible.

10. A source of origin, though present, may not be so related to porous beds that oil can have concentrated in them (for example, where the "mother rock" lies in a superficial formation, but the porous beds are thousands of feet beneath it).

11. Volcanic or plutonic rocks may abound in the vicinity and the geologist must inquire whether they have favorably or adversely affected the presence of oil.

12. Oil or gas may be present but unsuitable for commercial use in available markets.

13. The existing geologic structures may not embrace any of the well-known types in which oil is likely to occur in quantity. The structures must then be carefully studied to ascertain their value or bearing on oil occurrence.

14. Where artesian water exists under high pressure, it may have affected the concentration of oil adversely, but the mere presence of artesian water is not always unfavorable.

15. The position of the water level may be favorable or unfavorable with respect to the local structure. This position may be determinable or it may be indeterminable from the surface investigation.

16. The age of folding of the oil rock may be so much later than that of the stratum itself as to have permitted undue hardening or desiccation of the oil, or its alteration to torbinite or albertite before the favorable structures for its accumulation were formed.

17. Oil may have been removed in times past by human or natural agencies.

18. Sometimes topographic evidence of value exists, although in general unimportant or non-existent.

19. The formations may be of fresh-water or of marine origin. This is deemed by many to be a factor of importance.

20. The geologic "habit" of a region should be considered; for in some places there may be no observable single factor opposed to oil occurrence, yet some peculiarity of a criterion may be such as possibly to

modify the existing factors and render the locality more doubtful of results.

21. The region may be subject to frequent or violent earthquakes. In some countries these have been considered unfavorable, and it remains to be shown how far this pessimism is justified.

This list of factors that may need consideration is not an exhaustive one. The criteria are enumerated as a step in the complete diagnosis of an oil problem, and we all know that, even with the most complete studies, a decided possibility remains of the existence of some unknown, undecipherable, but unfavorable condition which may prevent the occurrence or commercial extraction of oil.

REMARKS ON THE SECONDARY CRITERIA

A few remarks on the secondary criteria may here be of interest. Although faults may not be dangerous, they do interfere somewhat with the *distribution* of oil in structures. For example, in connection with water circulation it is evident:[1]

> Where the water movement is up the regional dip, a strike fault may cause accumulation on its down-dip side by offsetting the reservoir bed and thus forming a sort of anticlinal trap. By deduction, where the water movement is down the regional dip, accumulation would take place in the up-dip side of the fault provided the fault cuts across a plunging anticline in such a way that the passage round the end is not free, and provided the water movement is not rapid enough to cause flushing.

For half a century after the discovery of petroleum in the United States a belief prevailed that faults were unfavorable to oil occurrence. The popular superstition against faults was so strong that for many years it permeated the geologic fraternity, some geologists remarking that certain prospective fields would never amount to much on account of the existence of faults. Even in reports of national and state geological surveys, some prospective fields were condemned because faults traversed them. In some countries this absurdity was expressed in the familiar words, "The country is too much broken up."

We now know that, under certain conditions, the presence of faults is actually favorable to the occurrence of oil. For example, Salt Creek field and Teapot dome are traversed by hundreds of faults, some having hundreds of feet displacement. Wells of high yield are found in these fields in proximity to faults and in some places actually cut them. Other fields in which faults are conspicuous are Elk Basin in Wyoming, the Mexia fault belt in Texas, and many of the Oklahoma fields. We can thus

[1] John L. Rich, *op. cit.*, p. 215.

say with authority that faults in themselves are not opposed to the existence of commercial oil; they may have furnished channels by which fluids have risen from deep-lying strata to those within reach of the drill, and they may have acted as traps to concentrate the oil in structure.

The importance of near-shore conditions for oil *accumulation* has been sometimes stressed, and this has constituted the subject of a paper before the Association.[1] The criterion was advocated on the basis of the supposition that the animals and plants from which oil is derived live in shallow water or in the zone not exceeding 25 fathoms in depth. The universality of this criterion does not appear to have been established. If true, it constitutes a phase of origin. In many cases oil probably originates under such conditions, but it may be formed in other paleogeographic relations also.

Although not a criterion of oil *occurrence* in a given district, natural gas is a factor propelling oil into wells from surrounding portions of a stratum in cases where the wells would otherwise be considered "dry"; hence, the existence and pressure of gas for propulsion is of importance.[2] Where gas pressure does not exist, the wells may not yield without pumping.

In most reports on oil-field probabilities, little or nothing is said about tectonics or widespread earth movements. Yet tectonics have their value as secondary criteria. As an example may be cited the question of whether geologic conditions of New Guinea and New Zealand are similar to, or different from, those in the East Indian Archipelago, where great producing fields exist. One cannot hastily jump to the conclusion that, because widely separated districts lie in a definite recognized tectonic belt, they must be similar geologically. If similarity exists throughout a belt, it is an additional argument in favor of oil occurrence, whereas if the deposition, folding, or faulting be of diverse ages from those in any known field, a report on the area would doubtless be less favorable.

CONCLUSION

This paper is not considered as covering the "secondary criteria." The few remarks made on those criteria are given merely to amplify the fundamental criteria enumerated, and the secondary criteria are to be made the subject of a later paper. This brief discussion of some of them will have illustrated their importance as a group and prepared the way for the later discussion.

[1] E. B. Branson, "Near-Shore Conditions Important in Locating Petroleum Deposits," *Oil and Gas Journal*, April 1, 1926.

[2] R. Van A. Mills, "Natural Gas as a Factor in Oil Migration and Accumulation in the Vicinity of Faults," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 14–21.

CABIN CREEK FIELD, WEST VIRGINIA[1]

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ABSTRACT

The Cabin Creek field is located in central West Virginia, 20 miles southeast of Charleston, on the Allegheny Plateau. It is owned and operated almost entirely by The Pure Oil Company, and is, therefore, an excellent example of unit operation. The pool is strictly a monoclinal accumulation close to the axis of a syncline. Production comes from the thickened lensed portion of the lower part of the Berea sand found at depths from 2,700 to 3,200 feet. The lens extends parallel to the synclinal axis, over an area 12 miles long by ½ mile wide. There is no water in the Berea sand, and, therefore, the accumulation is by gravity, the oil occupying the lens as far down the slope as the pay lens exists, with gas occurring up the slope to about 1 mile northwest of the oil field. The field has been developed since 1914 to the extent of 300 wells, but the known producing area is only a little more than half drilled. The oil averages 47° Bé., and is remarkable for its lubricating quality.

INTRODUCTION

Since this is the first report ever published on the geology of the Cabin Creek pool, West Virginia, an attempt has been made to present a fairly complete account of the field.

The Cabin Creek field is located in south-central West Virginia, about 20 miles southeast of Charleston. The oil always brings a better price than Pennsylvania grade, due to its excellent lubricating quality, and its high gravity, which averages 47°. Practically the entire pool is owned and operated by one company, The Pure Oil Company. Therefore, the development has been steady for the last 10 years. New wells are drilled to maintain a constant production. The production records are probably more complete than those of any other pool in the country. Each well has its own receiving tank so that the production has been kept for each well, each day, since the first well was drilled in December, 1914. The oil is run by gravity lines to the Cabin Creek refinery, also owned by The Pure Oil Company, 4 miles north of the field. Drilling and lifting costs are low as compared with the Mid-Continent fields. Ultimate production per acre is high compared with other eastern pools.

REGIONAL STRUCTURAL LOCATION

The Cabin Creek field trends northeast and southwest, parallel to the major structural axes of the state, as will be noticed on the map of West

[1] Read before the Association at the Tulsa meeting, March 25, 1927.

[2] The Pure Oil Company, 35 East Wacker Drive, Chicago, Illinois.

Virginia (Fig. 1). The pool is 12 miles long and ranges from ½ to 1 mile wide.

All other pools in West Virginia lie northwest of the Coalburg syncline, and its extension northeastward. This structure divides the state into two equal parts, a northwestern and a southeastern. Cabin Creek is the only pool southeast of the Coalburg syncline. The field lies well down

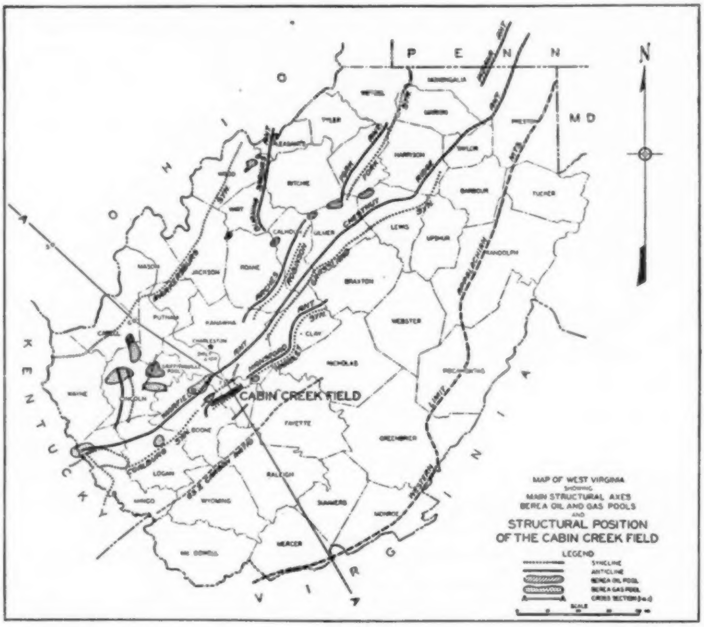


FIG. 1

the east slope of the Warfield anticline, which, with Chestnut Ridge, is the longest structure in the state. Cabin Creek is 75 miles northwest of the Appalachian Mountain front. It is 15 miles northwest of the 65 per cent isocarb, which is commonly assumed to indicate the limit of oil production. The 58 per cent isocarb passes through the Cabin Creek field.

OTHER BEREA POOLS

The other Berea oil and gas pools in the state are shown on Figure 1. Cabin Creek stands first in size of production; Griffithsville, in Lincoln

County, which is also located in a syncline, is second in size; and the Finck pool in Lewis and Doddridge counties is third. The Berea pools at Belmont, Pleasants County, and Hendershot-Ogden, Woods County, are among the earliest developed in the state. The Newberne and Revere pools in Gilmer County, Richardson pool, Calhoun County, and Milton pool in Cabell County were developed mostly before 1910. The only recently discovered oil pool in the Berea is at Liverpool, Wirt County.

TOPOGRAPHY

Cabin Creek is located on the Allegheny Plateau, which, in this area, is a highly dissected plateau in the mature state of erosion. The summits of the ridges rise to a common level; and on top the true plateau condition is clearly evident, as is shown in Figure 3. The natives call the area mountainous. With the elevations ranging from 800 to 1,600 feet, and with all the land surface in a slope of 20° to 30°, they are not far wrong. Drilling materials are delivered to wells on the ridges by a narrow-gauge railroad. This railroad has been moved several times as the drilling is carried southwestward.

EARLY HISTORY

DRILLING METHODS INVENTED IN THE GREAT KANAWHA VALLEY[1]

It is not generally known that all the essential machinery and methods for oil-well drilling in hard rock really originated in the Great Kanawha Valley, West Virginia, 12 miles northwest of the Cabin Creek field. Salt licks, which occur along the banks of the Kanawha, were frequented from time immemorial by Indian tribes and wild animals. The first white families in this region settled near these licks and boiled the salt water to acquire their meager supply of salt. In 1806, David and Joseph Ruffner set to work to ascertain the source of the salt water and to procure a supply equal to the growing demands of the country. They first set up a large hollow sycamore trunk. By one man with pick and shovel inside, and another man above with bucket and swape to lift the earth out, the hollow tree was lowered 17 feet, where they reached solid rock. In order to go deeper they fixed a long iron drill with a chisel bit and attached the upper end to a spring pole. By welding lengths of shaft to the drill, the hole was deepened during the next two years to 58 feet in the rock where sufficient brine was encountered to run their furnace. In order to get the brine undiluted to the surface, the problem of casing arose. They whittled out two half-tubes of wood, 40 feet long, external dimensions $2\frac{1}{2}$ inches, and wrapped the whole with small twine. This with

[1] *West Va. Geol. Surv.*, Vol. 1A, pp. 1–13.

a skin bag full of flaxseed, wrapped around the base, was pressed cautiously into place and served the purpose perfectly. Thus was the first well in the United States drilled, cased, and packed, 60 years before the first oil well was drilled.

In later wells, tin tubes soldered together replaced the wooden tube for casing. After that copper was used, and finally iron. Soon after this "slips" were devised for use in drilling. These were long, double links with jaws fitting closely together but sliding loosely up and down. These inventions gave great impetus to deep boring in the Kanawha Valley. The deepest well drilled in this early period was 2,000 feet.

EARLY HISTORY OF CABIN CREEK FIELD

In 1914, The Columbus Producing Company, a subsidiary of The Ohio Cities Gas Company, which later became The Pure Oil Company, acquired leases on a block of about 60,000 acres in southern Kanawha and northern Boone counties. They held other scattered tracts through counties to the northeast. This acreage had been taken mainly with the idea of developing gas and without any regard to geological conditions.

The first well, however, was located with care on the southeast flank of the Coalburg syncline, 8 miles southeast of the Warfield anticline, according to the geological map of Kanawha County, published in 1913, by the West Virginia Geological Survey. The location was placed far enough down the structure to have a chance for oil, yet far enough up to have gas possibilities also. When the Berea cap was reached there was a dead oil scum and hard white sand, which made it appear as though the well would be dry. After drilling 10 feet deeper, on December 18, 1914, the bit dropped into soft porous sand, the hole filled with light oil, and there was considerable gas. After a shot the well flowed 214 barrels for the first 24 hours. The well produced until the end of 1924, when it was shut in for gas. This well is located in the northeastern end of the field (Fig. 1), which was drilled up rapidly in the next few years. Later development jumped across Mount Hope, which is the divide between Kanawha and Coal rivers; and some of the best wells in the field have been drilled on Joe's Creek, a tributary of Coal River.

Of the wells drilled by The Pure Oil Company, 268 were oil wells, 6 were gas wells, and only 7 were dry holes. Several of the dry holes were drilled to outline the limits of the pool.

STRATIGRAPHY

PENNSYLVANIAN SURFACE

The rocks of the surface consist of sandstones, shales, and coals of the Allegheny and Pottsville groups of the Pennsylvanian. Benches at

coal-bed levels are plentiful and massive sandstones on the hillsides commonly weather "chimney"-fashion. Minor drainage is generally closely related to local dips. The regional dip is northwest, but in the Cabin Creek area this dip is practically overcome by the Warfield anticline and Coalburg syncline. The surface contouring was worked on the Cedar Grove coal of the Allegheny series.

PENNSYLVANIAN SUBSURFACE

The Pennsylvanian rocks are about 1,400 feet thick, and consist largely of sands and thin limes and shales. In this formation the "Grampus," the drillers' term for a hard sand found near sea-level, has an average thickness of 150 feet. The "Salt Sand," named from its saline water, is a bed 50 to 75 feet below the "Grampus," and is the basal member of the Pennsylvanian. The unconformity at the base of the Pennsylvanian is not angular, but merely one of erosion. The basal sands have filled in all irregularities on the Mississippian floor.

MAUCH CHUNK

Below the Pennsylvanian is the Mauch Chunk, consisting of characteristic red shales, limestones, and non-persistent sand bodies. The "Maxon" sand belongs to this group. The Mauch Chunk was laid down in the Appalachian geosyncline with successive overlaps to the west, until, at its widest extent, it reached nearly to Ohio River.

GREENBRIER

Conformably below the Mauch Chunk is the Greenbrier limestone, the "Big Lime" of the driller, which is equivalent to the Maxville of Ohio. The Greenbrier lime consists of the "Little Lime" member, about 100 feet thick, the "Pencil Cave," 8 to 20 feet thick, and the "Big Lime," 200 feet thick. Drillers sometimes miss the "Pencil Cave" and record the two limes as one. The "Keener" is any sand found within and near the bottom of the "Big Lime." Immediately below the lime is the "Big Injun," about 30 feet in thickness. The "Big Lime," "Keener," and "Big Injun" may be correlated with the "Big Injun" of northern West Virginia.

POCONO

The Pocono series is about 400 feet thick and includes the "Squaw" and "Wier" sands. Both terms are rather loosely used, since the sands are not uniform. The "Squaw" is applied to any oil- or gas-producing sand not far above the Berea "Grit." The "Wier" and "Squaw" sands, probably one horizon in Cabin Creek, have good showings of gas generally scattered throughout the area. They are most frequently found in the wells on Joe's Creek.

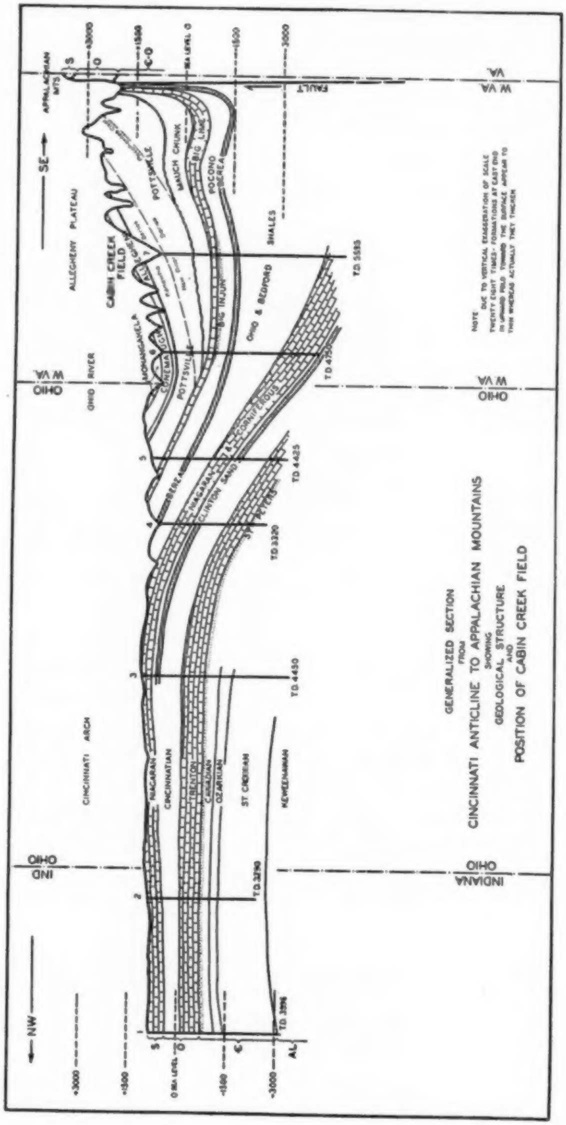

GENERALIZED SECTION
FROM
CINCINNATI ANTICLINE TO APPALACHIAN MOUNTAINS
SHOWING
GEOLOGICAL STRUCTURE
AND
POSITION OF CABIN CREEK FIELD
NW
SE
CINCINNATI ARCH
ALLEGHENY PLATEAU
APPALACHIAN MTS
CABIN CREEK FIELD
OHIO RIVER
IND
OHIO
INDIANA
W VA
VA
FAULT
NIAGARAN
CINCINNATIAN
TRENTON
CANADIAN
OZARKIAN
ST CROIXIAN
KEWEENAWAN
MONONGAHELA
CONEMAUGH
POTTSVILLE
MAUCH CHUNK
BIG LIME
BIG INJUN
POCONO
BEREA
SHALES
OHIO & BEDFORD
CORNIFEROUS
CLINTON SAND
ST PETERS
SEA LEVEL 0
T.D. 2790
T.D. 3320
T.D. 4425
T.D. 4430
T.D. 5585

FIG. 2

The Coffee shale, which is equivalent and strikingly similar lithologically to the Sunbury shale of Ohio, occurs immediately over the Berea. This shale is a thin, platy, "stinking," brown shale and is rarely missed by the driller. It is, therefore, an excellent marker for the Berea. Its average thickness is 12 feet.

BEREA

The Berea is the producing sand of the Cabin Creek field, and therefore demands more attention than formations above or below. It is quite clearly a near-shore sand deposit of an advancing sea. It is the basal member of the Mississippian, and is remarkable for its uniform thickness and purity over a very large area. The Berea occurs in West Virginia, Pennsylvania, Ohio, Kentucky, and Michigan, in all of which states it is productive.

TABLE I

DEEP WELLS USED IN THE CROSS SECTION, FIGURE 2

Well Name	County and State	Elevation in Feet	Reference
1. Greentown*..	Howard, Ind.	840 est.	*Ind. Geol. Surv. Bull.* 55 (1926), p. 256.
2. Bryant*.....	Jay, Ind.	870 est.	*Ind. Geol. Surv. Bull.* 55 (1926), p. 282.
3. Friend, D.T..	Clark, Ohio	1,100 est.	Not published. Log and samples, Pure Oil Co., Geol. Dept. Location: 11½ mi. SE. Springfield, Ohio.
4. Waverly.....	Pike, Ohio	600 est.	*Amer. Jour. Science*, Vol. 31, p. 19.
5. Martin......	Jackson, Ohio	872	*Ohio Geol. Surv.* files.
6. Templeton...	Cabell, W.Va.	585	D. B. Reger, "First Test of Clinton Oil Sand in W.Va.," Feb., 1925, Meeting, *Amer. Inst. Min. and Met. Eng.*, p. 3.
7. Edwards.....	Kanawha, W.Va.	640	*W.Va. Geol. Surv.*, Kanawha Co. Rpt. (1914), Intro. XVIII.

* Correlation from samples by Dr. Logan, state geologist, Indiana.

At Cabin Creek, the Berea has a range of 15 to 52 feet in thickness, with an average of about 35 feet. It is divided into two parts, cap above and pay below. This relation is brought out by Figure 5. The thickness of the cap is uniform in the field, averaging 15 feet, although it thins both northwest and southeast of the field. The cap is clear, white, hard quartzite, drilling always as fine chips, never as grains. The quartzitic structure is evident from the smooth glistening surface of a freshly broken piece. Under the microscope the built-up sand grains, which interlock, are clearly seen. Its porosity, by Melcher's method, gives only 4 per cent.

The pay occurs without a break below the cap, and the transition seems to be fairly sharp. The pay is 35 feet thick in the best part of the

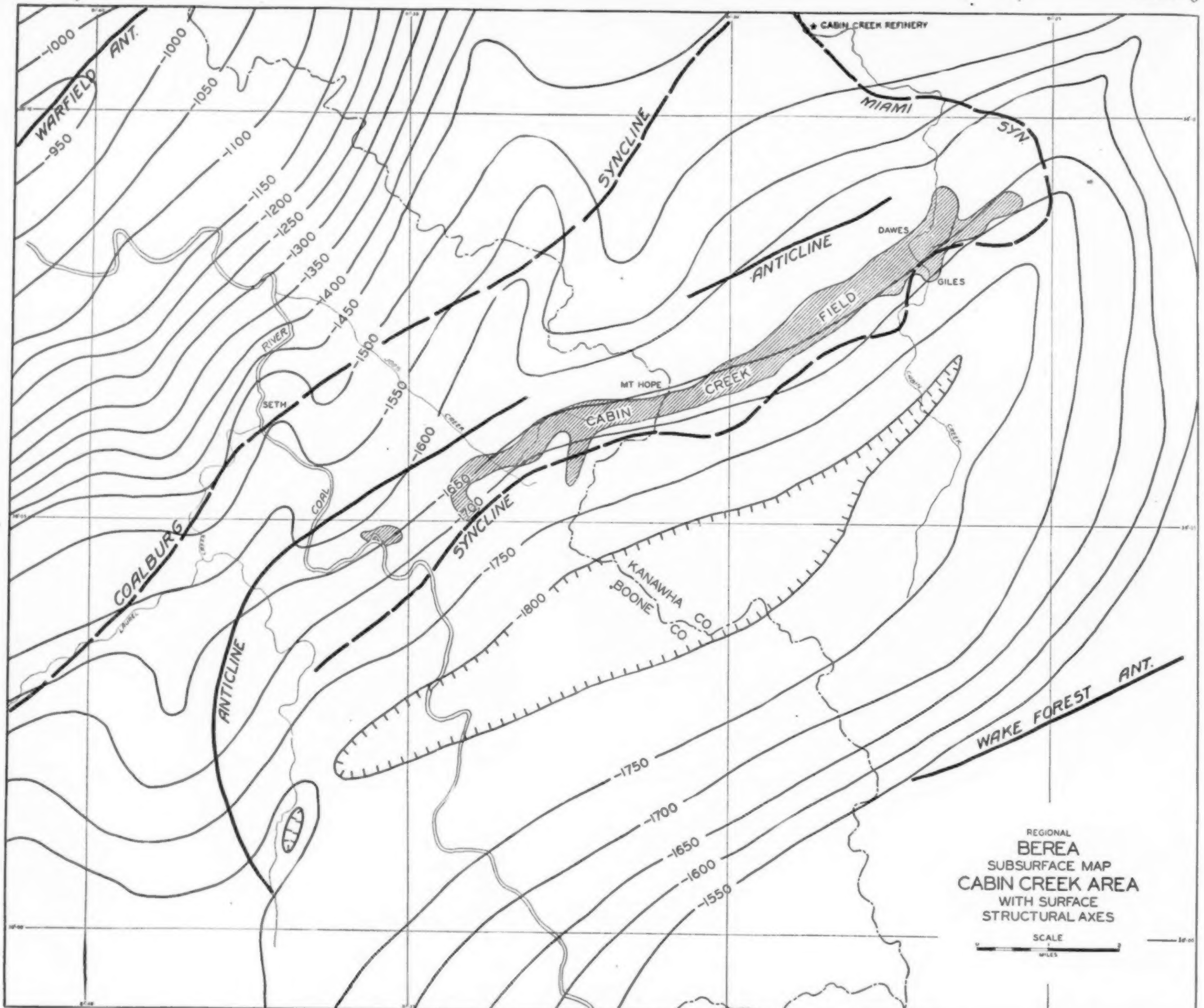
pool but it pinches out on the southeastern side of the field. The limits of the field to the northeast and southwest are controlled by this pinching out of the pay. The cap is continuous; the pay is a lens below the cap. The deduction follows that where the total Berea thickness is less than 15 feet, it is all cap. The limit of the field on the southeast side is determined by the non-existence of the pay. The Berea pay is pure quartz sand with here and there flaxseed bodies of dark shale. The texture of the sand ranges from very fine-grained to pebbly. The pebbles are small, white and well rounded. This pebbly phase is erratic, occurring in thin streaks, or patches of small extent. The grains are angular and most of them sparkle under a lens. There is little cement, the sand drilling easily into individual grains. The porosity averages about 16 per cent.

DEVONIAN

Formations below the Berea have been tested by three wells, which were located in the northern part of the Cabin Creek area. None has found any sand which might induce deeper drilling. The deepest test was the Edwards well, No. 7 on the cross-section Figure 2, Table I. This well penetrated nearly 3,000 feet of black Devonian shale below the Berea, and near its total depth of 5,595 feet entered the Corniferous lime. The Bedford shales thicken so rapidly from Ohio toward the Appalachian Geosyncline that drilling for Corniferous or Clinton production is very discouraging.

REGIONAL STRUCTURE

Regionally, the Cabin Creek field is located on the eastern slope of the Appalachian geosyncline. The cross-section (Fig. 2), whose trace is shown for West Virginia on Figure 1, was made to show the structural relation from the Appalachian front, at East River Mountain, across West Virginia, Ohio, and into Indiana. It is constructed from deep wells, which are tabulated for further reference (Table I) and from surface work along East River Mountain. The surface profile is drawn to scale from United States topographic maps. At the base of this mountain there is a fault, with at least 6,000 feet of throw, since Devonian beds, which are known to be 6,000 feet deep, are brought to the surface, while the mountain on the east side of the fault is composed of Cambro-Ordovician and Silurian limestones. The dominant features, as brought out by the section, are the restricted basins of sedimentation and the consequent thickening of sediments toward the geosyncline, as indicated especially by the Mauch Chunk and Pottsville and the tilting of these sediments toward the west with the rise and folding of the Appalachian Mountains. The


REGIONAL
BEREA
SUBSURFACE MAP
CABIN CREEK AREA
WITH SURFACE
STRUCTURAL AXES
SCALE
MILES
CABIN CREEK REFINERY
WARFIELD ANT.
MIAMI SYN
SYNCLINE
ANTICLINE
DAWES
GILES
CABIN CREEK FIELD
MT HOPE
SETH
COAL RIVER
COALBURG ANTICLINE
SYNCLINE
KANAWHA CO
BOONE CO
WAKE FOREST ANT.
-950
-1000
-1050
-1100
-1150
-1200
-1250
-1300
-1350
-1400
-1450
-1500
-1550
-1600
-1650
-1700
-1750
-1800

Pocahontas coal indicates the degree of tilting at its maximum. The section shows also that the youngest formations of the Pennsylvanian, the Conemaugh and Monongahela, occur along Ohio River, where the Parkersburg syncline has made for their preservation.

The cross-section is extended northwest, mainly on account of the very interesting Friend well (Fig. 2, No. 3). This well was drilled in 1925 and 1926, located high up on the Cincinnati Arch. Instead of entering granite below the Magnesian lime, as was expected, it went through nearly 2,000 feet of Cambrian sand and limestones.

FIG. 3.—Remarkable winter scene on the mountains at Cabin Creek. An imposing scene from the top of one of the mountains above Dawes, West Virginia. Note the pyramid effect, which was obtained by getting the picture when the sun was at the right place and when there was just enough snow to outline the mountains.

STRUCTURE OF CABIN CREEK POOL

The Cabin Creek pool is strictly a monoclinal accumulation, found in the thickened lensed portion of the lower part of the Berea sand, well down the side of a syncline. The lens extends parallel to the synclinal axis in a long narrow strip over an area 12 miles long by ½ to 1 mile wide.

As shown in Plate 5, the surface coal structures at Cabin Creek are not reflected in the subsurface Berea structures. From the surface axis it appears as though the pool is located between two subordinate structures, a short anticline and a syncline running along the south edge of the field. On the Berea these structures are not present; neither is the Coalburg

syncline, which is located northwest of the field by the West Virginia Geological Survey, and is one of the main surface structures in the state. The Berea does reflect the Warfield anticline, which is about 9 miles northwest of the pool. Here the Berea axis is located nearly under the surface axis. The Berea slopes from the crest of the Warfield anticline from -950 feet to $-1,800$ feet, at the rate of 85 feet per mile, across the Cabin Creek pool, into a basin located about 2 miles southeast of the field, from which it rises to the Wake Forest anticline, $4\frac{1}{2}$ miles to the southeast,

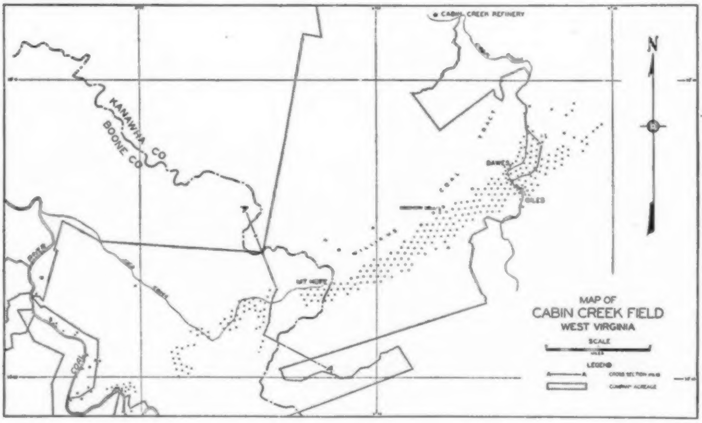


FIG. 4

where it has an elevation of $-1,550$ feet. The pool occurs between the $-1,600$- and $-1,700$-foot contours. There are a few minor nosings across the field, which have widened the pool at those points.

ACCUMULATION

The Berea contains no water; therefore the oil fills the lens as far down on the synclinal slope as the pay lens exists. At the upper edge of the field gas occurs, and continues some distance toward the Warfield anticline. As there has been little drilling in the gas territory, the upper limit of the gas reservoir is not definitely known. It is located between 1 and 2 miles northwest of the pool. Sand conditions and gas, rather than structure, are more important in controlling production at Cabin Creek.

The present rock pressure of wells on the upper side of the field ranges from 20 to 185 pounds, as compared with an original rock pressure in

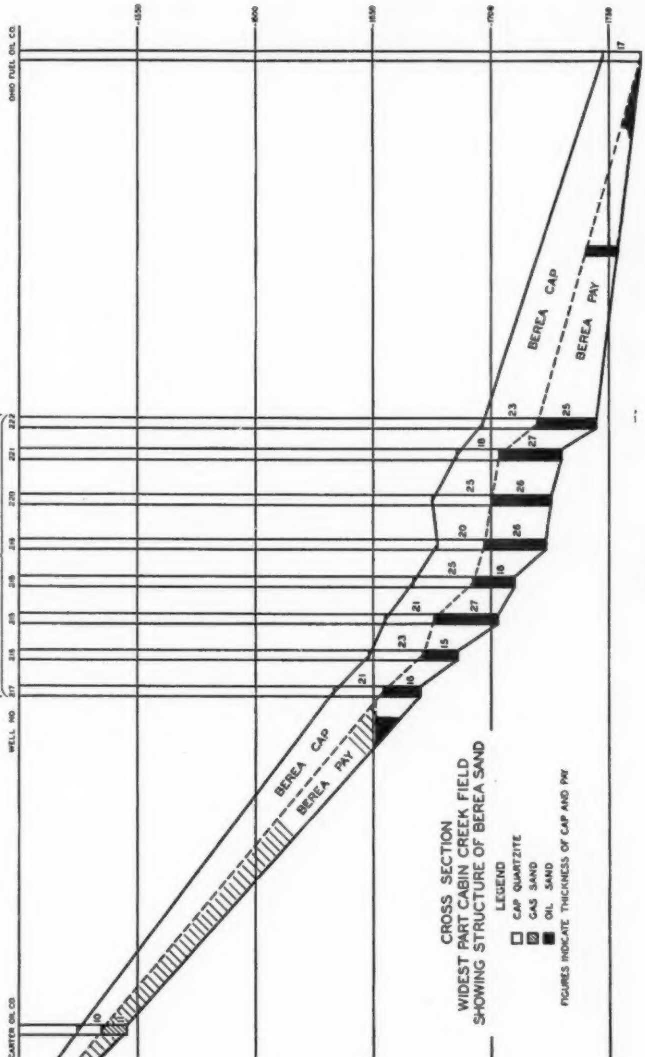

CROSS SECTION
WIDEST PART CABIN CREEK FIELD
SHOWING STRUCTURE OF BEREA SAND
LEGEND
CAP QUARTZITE
GAS SAND
OIL SAND
FIGURES INDICATE THICKNESS OF CAP AND PAY
CABIN CREEK FIELD
THE PURE OIL CO. WILLIAMS COAL TRACT
WELL NO
CARTER OIL CO
OHIO FUEL OIL CO.
BEREA CAP
BEREA PAY
BEREA CAP
BEREA PAY

FIG. 5

excess of 300 pounds. The present average is about 100 pounds. Existing rock pressures along the southern edge of the field range from 10 to 100 pounds, with an average of about 60 pounds.

The reason for the present lack of water in the Berea is still a problem. This condition is common throughout the Berea of West Virginia except near the western edge. Even in the bottom of the synclines, water is not reported in the Berea. The sand must have had water at the time of deposition, for it is distinctly a marine sand. The lens at Cabin Creek may have been an off-shore deposit. It is possible that an ancient barrier may have existed along the present location of the Warfield anticline which held the shore line stationary during this deposition, for the Berea over the anticline is thin and non-productive. The pebbly streaks in the Berea, and the purity of the quartz are evidence of marine origin. It is also certain that the sand contained water when the upper portion was made into a quartzite. Possibly the water in the lower portion of the lens was stagnant, whereas the upper waters were circulating. Hence the non-porous cap and open pay.

Probably the oil formed in the Devonian shales and migrated into the Berea sand during the Appalachian revolution. Due to heat, under pressure, the oil may have been distilled and entered the sand largely as a gas, dispelling the water. As the gas cooled, the oil vapors condensed and gathered by gravity down the dip into the lower part of the pay lens, the gas occupying the upper part.

CABIN CREEK OIL

The oil is light amber in color, clear, and thin, with a strong gasoline odor. Its gravity averages 47°. It has a paraffin base, and on being cooled becomes clouded. By keeping the oil standing in a column over the sand, paraffining of the sand is not a problem.

The oil is remarkable for its lubricating quality. The ratio of hydrogen to carbon is high, which makes the lubricating oil appreciably more stable under heat than that from other Pennsylvanian grade oils, and it is for this reason largely that it brings a price above Pennsylvanian crude.

DEVELOPMENT

WELL SPACING

The well spacing until recent times has been uniformly 700 feet on radial lines at 60° to each other. By this arrangement there was one well to 9.3 acres. The spacing being used at present is 600 feet, making 7 acres per well. Along the right of way near Dawes, at the northeast end of the

field, where some offsets were drilled by other companies, wells were spaced much closer, the average being 200 feet.

PRODUCTION HISTORY

The almost total absence of production data on other eastern pools makes it difficult to show the important position Cabin Creek holds in the East. To those more familiar with the large Mid-Continent pools, the oil yields from Cabin Creek appear to be comparatively unimportant. However, due to the fact that the average price per barrel for Cabin Creek crude has been about twice that obtained for 40° crude in Mid-Continent fields through the same period of years, the net returns to the operator are correspondingly doubled, and the field is given a special significance.

TABLE II

ANALYSIS OF CABIN CREEK CRUDE
Gravity 46.7°. Sulphur 0.018 Per Cent

Cut	Grade	Per Cent Crude	Degrees Gravity	Flash	Fire	Vis/100	Pour
Over to 50.4	Crude naphtha	45	60.1	....	....	....	....
50.4–42.4	Kerosene distillate	15	45.3	154	....	....	....
40.6–38.4	Gas oil	5.0	38.4	280	325	....	....
38.4–Off	Wax distillate	18	34.2	360	410	93	70
Bottoms	Cylinder stock	13.27	26.9	545	615	155/210	....
Loss	....	2.98	....	....	....	....	....

The average cost of drilling the 2,700- to 3,200-foot wells has been about $15,000 per well. With an efficient gasoline plant, with the oil run by gravity lines to the refinery, 4 miles away, this field is a complete unit.

The field can be divided into four main parts: a northeastern, a central, the Joe's Creek, and the Coal River portions (Fig. 4).

The northeastern end extends from the discovery well northeastward, and includes about 100 Pure Oil, and about 50 outside wells. This portion is completely drilled. The initial production per well, on company acreage, ranges from 10 to 200 barrels, with the exception of a few wells having an initial production as large as 400 barrels. The average initial production was about 50 barrels.

The central portion extends from the discovery well to the Boone-Kanawha County line at Mount Hope. This also includes about 100 wells, although it is perhaps only three-fourths developed. This portion is much more productive than the eastern end, with the larger wells along the upper side. The range for initial production is the same as for the northwestern zone, but with a higher average.

The Joe's Creek portion extends from Mount Hope to a point about a mile northeast of Coal River. It includes about 100 wells, but is only about one-third developed. The development along Joe's Creek is the most productive portion of the field. It is also most spotted in size of wells. The very large wells seem to be arranged singly, or in small groups, suggesting local sand conditions as being of prime importance.

The wells at the Coal River end are very small, and the oil pool terminates not far below the river.

From a study of the ultimate production per well it is found that the larger wells are located along the upper side of the field, the smaller along the lower side.

DECLINE CURVES

From a study of the rate of decline of the wells it is evident that those most rapidly declining are on the upper side, with the more slowly declining ones on the lower side. This relation holds true everywhere, except from Mount Hope for about 2 miles along Joe's Creek. In this portion, where the largest wells are located, all are slowly declining.

UNIT OPERATION

The development of the Cabin Creek field is an example of what can be accomplished by a single company, or what is, in its essence, unit operation. Development has been definitely regulated to satisfy the needs of the company refinery at Dawes, which fluctuate somewhat, due to market demands. Forced drilling to satisfy offset requirements has been largely avoided. As there is no demand for rapid drilling, information from each new well can be used in making new locations, with the result that dry holes are negligible. Over-production is prevented, gas and oil waste are eliminated, drilling and operating costs are reduced to a consistent minimum, and excess equipment, for short-time use, has been unnecessary.

DISCUSSION

A. C. Boyle, Jr.: A significant fact brought out in Mr. Wasson's paper is that a bed of sand may function as a reservoir as well as an impervious capping. The upper portion of the Berea sand has been locally cemented by minerals carried into it and deposited by the action of circulating waters prior to the accumulation of the oil. To my mind this is a distinct contribution to the influence of structure as modified by cementation, and this may explain the minor variations of depth as often noticed in many of our oil wells. It would be interesting to learn more about the chemical and mineralogical character of the cements.

F. G. Clapp: I should like to ask if there is any evidence of water in the

basin east of the Cabin Creek field; also if there is a possibility of small amounts of water in the Berea sand which have not been detected?

THERON WASSON: There has been no evidence of water in the bottom of the syncline east of the Cabin Creek field. The question of small amounts of water in the Berea cannot be answered definitely. The sand may be moist, but until we have better evidence in the form of continuous cores through the sand body, we do not know.

QUESTION: How many wells have been drilled at Cabin Creek?

ANSWER: Three hundred wells have been drilled to date.

QUESTION: The cross-section of the Berea seemed to show two sands. Is that true?

ANSWER: There are not two sands. The cross-section showed an upper layer of impervious cap, which is quartzitic and drills up as sharp chips. This changes into the softer sugar-sand pay which is beneath.

QUESTION: What decrease has been noted in the gas pressure on the upper side of the field since development started?

ANSWER: The original rock pressure was about 300 pounds. The present rock pressure averages about 100 pounds.

QUESTION: What limits or controls the gas up the dip? Does it lense out?

ANSWER: The pay sand changes in character up the dip, becoming more silty and impervious. This is equivalent to lensing out.

STRATIGRAPHIC POSITION OF THE BIG LIME OF WEST TEXAS[1]

EVERETT C. EDWARDS[2]
San Angelo, Texas

ABSTRACT

Rapid oil developments in west Texas make necessary an interdistrict correlation for the petroleum geologist.

Geologically, west Texas is a structural geosyncline, and during Permian times it was a basin of deposition.

The Permian sea invaded from the southwest. Clastic sediments were derived from ancient Llanoria, from the Wichita Mountains, the igneous ridges of the Panhandle, and from the Ancestral Mountains of New Mexico. This material formed a border of red clastic sediments around the landward portion of the Permian sea, which, traced seaward in directions normal to the strand lines, grades into marine sediments, chiefly dolomitic limestones.

The latter constitute what is called the "Big Lime" series. The top of the Big Lime is the key bed used in subsurface work in west Texas. The upper part of the Big Lime is found to be of Double Mountain age, and may correlate with the Word formation of the Glass Mountain area and the Delaware formation of the Trans-Pecos area. It is considerably higher stratigraphically than the Big Lime of the Panhandle district.

Following the deposition of the Big Lime, a closed or restricted basin developed, the result being that the upper Permian measures are composed chiefly of anhydrite and salt, deposited from super-saline water.

INTRODUCTION

The economic importance of west Texas needs no introduction to the oil industry.

Structurally, west Texas is a large geosyncline. Detailed studies of the stratigraphy of this area have been made along the truncated outcrops of the Permian measures around the periphery of this geosyncline. These studies have been made public in state and federal bulletins, but thus far very little has been published about the stratigraphy of the Permian basin proper, that extensive area where oil and potash are found, and where the Permian is concealed by Mesozoic and later systems.

The area described in this paper lies between 100° and 105° West Longitude, south of the Panhandle, and north of the Marathon Mountains.

[1] Read before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor April 4, 1927.

[2] Geologist for the Exploration Company of Texas, 303 Mays Bldg., San Angelo, Texas.

The position of the Big Lime in the stratigraphic column is important because it is a blanket deposit underlying most of west Texas, and is the key bed most frequently used for subsurface control. Because of its wide areal distribution, it gives promise of serving as the key formation common to all of the separated districts.

GENERAL STRUCTURE

As mentioned in the introduction, the structure of west Texas is that of a geosyncline. The eastern margin is defined by the Bend Arch. The southern margin may be considered as a line extending from the Marathon Mountains to the central mineral region, or Llano uplift. The western side is limited by the mountains of southeastern New Mexico and the Delaware and the Apache mountains of Texas. The granite ridges of the Panhandle district, and the Ancestral Rocky Mountains of New Mexico may be taken as the northern limit. The area within these limits appears to be one big geosyncline comprising a geologic province.

BASIN OF DEPOSITION

This area in west Texas, which is at present a structural geosyncline, during the Permian period was a basin of deposition. This fact is important because the stratigraphic sections in different parts of the basin are definitely related to such factors as Permian land masses, strand lines, and marine areas. The ancient land, Llanoria, which lay south and east of the area under discussion, and which was a land mass from pre-Cambrian until Cretaceous times, contributed the greater part of the clastic material found in the Permian series of west Texas.

GENERAL STRATIGRAPHY

EAST SIDE OF THE BASIN

Along the east side of the basin, immediately west of the Bend Arch, the truncated outcrops of the Permian strata have been studied and described. They have been subdivided into three formations: the Wichita-Albany, the Clear Fork, and the Double Mountain (Fig. 1).

The Wichita-Albany formation is the lowest. It is typically a marine deposit, consisting chiefly of dolomitic limestone and blue shale, with some sandstone, principally at the base. It represents the farthest invasion of the Permian sea over the area previously occupied by the Pennsylvanian. There is no marked structural or depositional break between the Pennsylvanian and the Permian. The only noticeable contrast is that the Cisco contains considerable red sand and red shale, indicating transportation

and deposition of clastic material from adjacent land masses. In the succeeding Wichita-Albany epoch, the adjacent land masses must have had very little relief, because the sediments are practically all of the marine type. The Wichita-Albany formation is about 1,200 feet thick.

Overlying the Wichita-Albany is the Clear Fork, which is a mixed continental and marine deposit. Except for a small amount of dolomite and blue shale, the Clear Fork outcrop consists entirely of red sandstone and red shale. It is 900–1,000 feet thick.

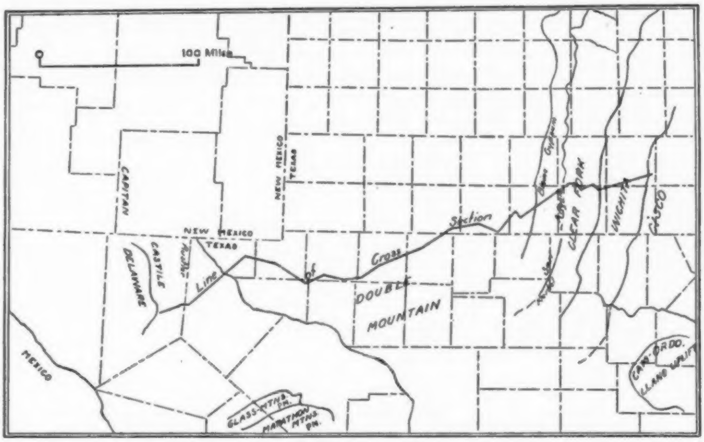


FIG. 1.—Map of west Texas showing formation boundaries and line of cross-section.

Above the Clear Fork is the Double Mountain formation. At the outcrop this consists of red sandstone, red shale, and gypsum. The entire thickness of the Double Mountain group cannot be measured along the outcrop, because it dips constantly westward, passing under the Mesozoic and later systems. Its total thickness can only be obtained from logs of wells drilled in the center of the basin. From this source of information its maximum thickness may be given as more than 4,000 feet. There it is composed of red sandstone and shale, anhydrite, salt, polyhalite, and dolomitic limestone.

POSITION OF THE BIG LIME ON THE EAST SIDE

From their outcrops, these formations have been traced underground into the basin by comparison of the logs and samples of the intervening

wells. As shown in the accompanying cross-section (Plate 6), the lithology at the outcrop is radically different from the lithology of these same formations as logged in the wells. The one exception to this is the Wichita-Albany formation, which preserves a marine facies throughout its entire extent, as represented in this area.

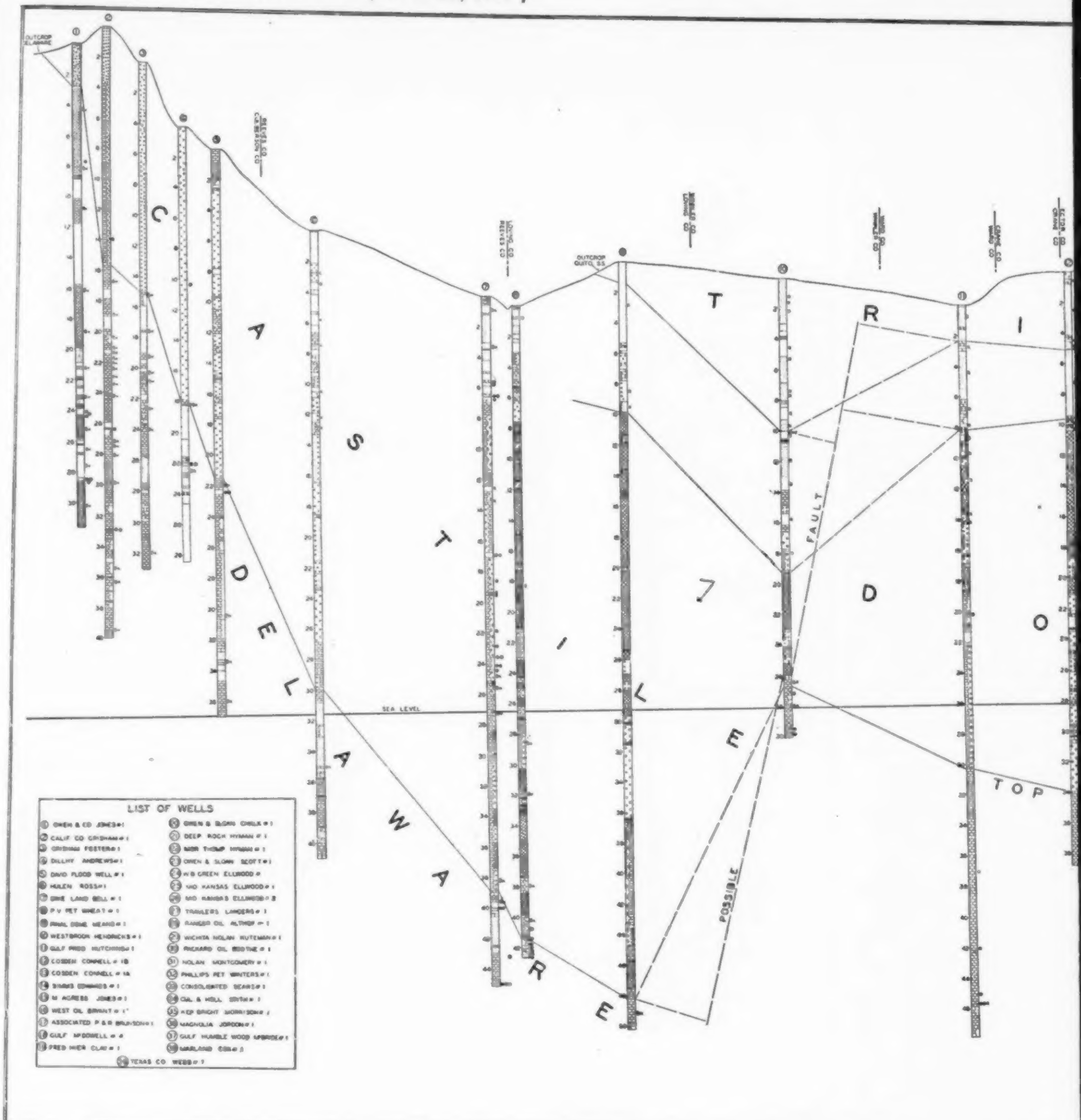
Although the Clear Fork consists almost entirely of red clastic material on the truncated outcrop, it has graded laterally into a dolomitic limestone in the basin proper. This is due to the fact that the clastic material has thinned out and disappeared in a seaward direction, and its place in the stratigraphic column has been taken by typical marine deposits.

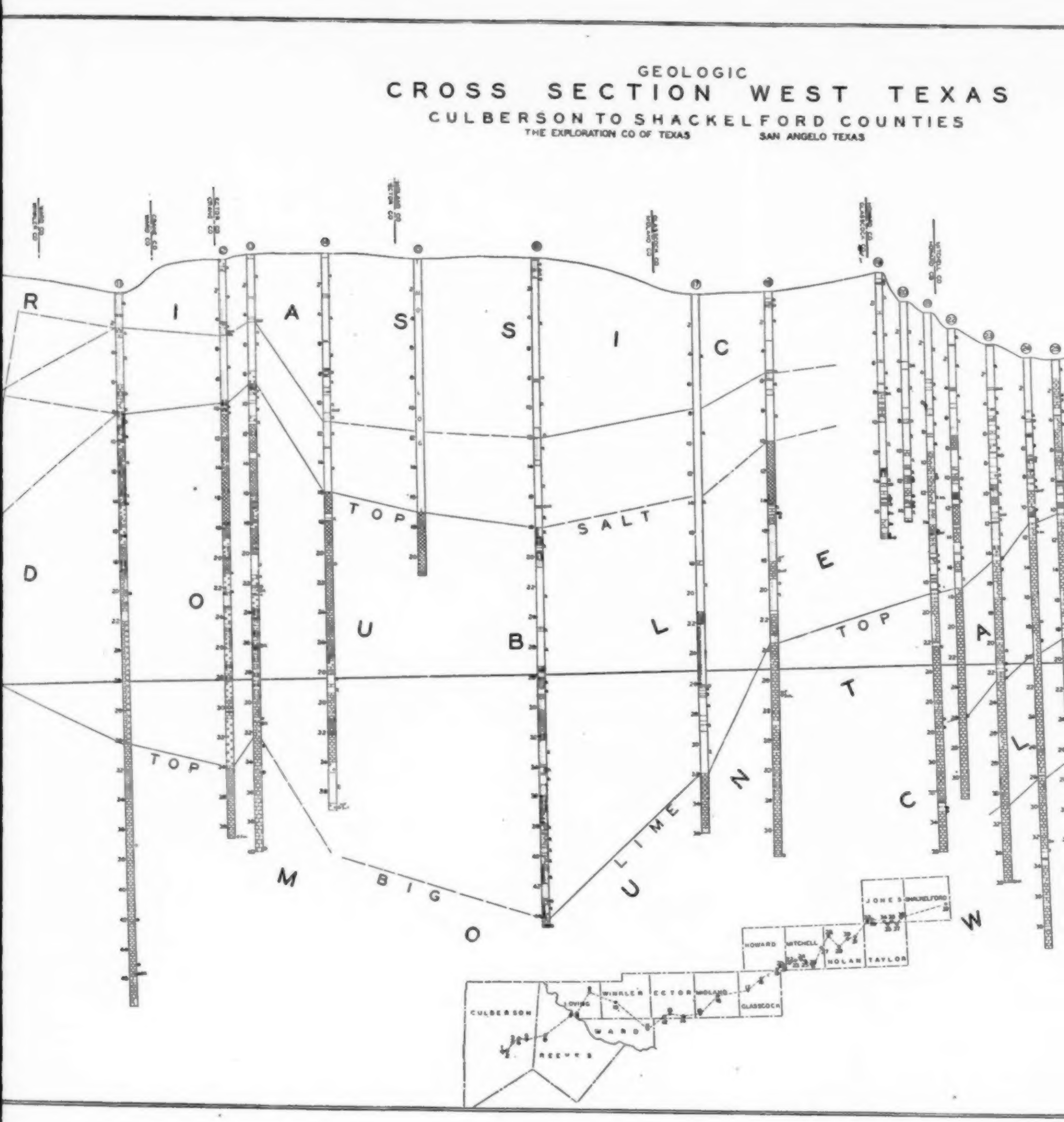
During the lower Double Mountain epoch the same processes of deposition continued which were operative during the Clear Fork. The red beds of the Double Mountain, as high up as the Blaine gypsum formation, have graded out to the west, their place being taken by marine calcareous deposits which form the Big Lime.

During the Clear Fork and the lower Double Mountain epochs, the adjacent land mass to the east was evidently rising intermittently, each new uplift causing a flood of red clastic material to be thrown into the Permian sea and along the shore. These occasional uplifts resulted in the deposition of extensive wedges of clastic material, which gradually thin out and disappear toward the west, far out in the basin. They are separated from each other by deposits of dolomitic lime and blue shale, which conversely wedge out and disappear toward the east. The wedges of red beds are very helpful in unraveling the correlation of the east side of the basin. They are easily detected and are usually logged by the driller. Their alignment in the different wells can be used as a gauge to show the correlation and rate of dip of those formations which are less recognizable.

Three definite wedges of red beds can be named. One occurs at the base of the Clear Fork, one in the middle of the Clear Fork, and one at the base of the Double Mountain formation, the latter occupying the stratigraphic position of the San Angelo conglomerate of Texas and the Duncan sandstone of Oklahoma. A cross-section, if drawn along a line parallel to the strand lines, would illustrate that the lithology is practically the same throughout the entire distance.

The top of the Big Lime, when projected to the outcrop, is found to be at the base of the Blaine gypsum formation, and is about 700 feet above the Merkel dolomite. Therefore it can be placed definitely within the Double Mountain formation.


C A S T I L E
D E L A W A R E
T R I D O
FAULT
POSSIBLE
SEA LEVEL
TOP
LIST OF WELLS
CALIF CO GRISHAM #1
DAVID FLOOD WELL #1
WESTBROOK HENDRICKS #1
COSDEN CONNELL #1A
GULF McDOWELL #4
DEEP ROCK HYMAN #1
OWEN & SLOAN SCOTT #1
W B GREEN ELLWOOD #
MID KANSAS ELLWOOD #1
NOLAN MONTGOMERY #1
PHILLIPS PET WINTERS #1
CONSOLIDATED SEARS #1
MAGNOLIA JORDON #1
TEXAS CO WEBB #7


GEOLOGIC
CROSS SECTION WEST TEXAS
CULBERSON TO SHACKELFORD COUNTIES
THE EXPLORATION CO OF TEXAS
SAN ANGELO TEXAS
TOP SALT
TOP
TOP
BIG LIME
CULBERSON
LOVING
WINKLER
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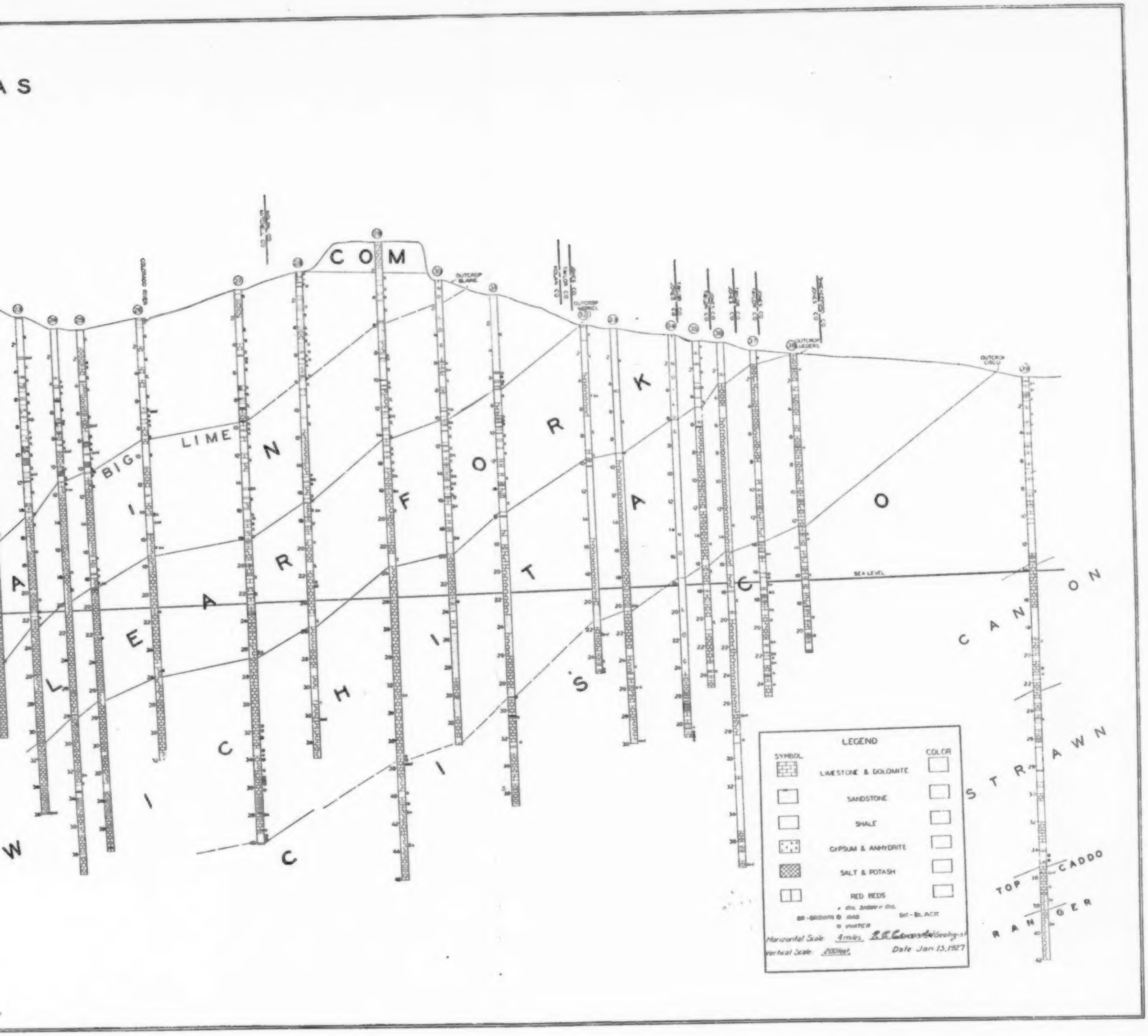
JONES
SHACKELFORD
TAYLOR


COM
BIG LIME
SEA LEVEL
C A N
O N
S T R A W N
TOP CADDO
R A N G E R
LEGEND
SYMBOL
COLOR
LIMESTONE & DOLOMITE
SANDSTONE
SHALE
GYPSUM & ANHYDRITE
SALT & POTASH
RED BEDS
Horizontal Scale 4 miles
Vertical Scale 200 feet
Date Jan 15, 1927

TOP OF THE BIG LIME IN THE BASIN

In the basin no limestone formations are found above the top of the Big Lime. It is overlain by red beds, anhydrite, and salt.

Salt has not been encountered below the top of the Big Lime in any of the wells drilled thus far.

The appearance of thick formations of salt and anhydrite in the stratigraphic column indicates that the conditions of deposition had undergone a decided change. The anhydrite and salt must have been laid down in a closed, semi-closed, or restricted basin. It seems logical to assume that the contact between the Big Lime series and the overlying anhydrite and salt series marks the time of the restriction of the Permian sea. This assumption will be used later in discussing the probable stratigraphic position of the Big Lime on the west side of the basin. Its importance is substantiated by the fact that at the end of the deposition of the Big Lime, certain deformative movements took place, which affected the lime, but not the overlying beds.

It is not everywhere an easy task to locate the contact between the two series. In places the break is distinct. Elsewhere there is a transition zone present through which the anhydrite grades imperceptibly into dolomitic limestone. In places small amounts of anhydrite are found below the top of the lime. In the basin proper, the top of the lime cannot be determined from drillers' logs. Most drillers log anhydrite as lime. This means that the contact between the two series must be obtained from an examination of the samples taken from the wells.

Where it is difficult to place the contact, adjacent beds may be used as checks. There are the brown sandy dolomite, the white lime, the bentonite horizons, the sulphur-water zone, and others. In practically all cases the lime is overlain, first by anhydrite, and then by salt.

It is thus seen that the change in depositional conditions in the basin was gradual rather than sudden.

THE BIG LIME OF WEST TEXAS AND THE BIG LIME OF THE PANHANDLE DISTRICT

The conditions of lithology and deposition represented in the eastern part of the cross-section are somewhat similar to the conditions south of the Panhandle.

The Big Lime of the Panhandle appears to be Wichita. A short distance to the south, the first lime encountered by the drill is Clear Fork. From Dickens County south and west, and including that county, the uppermost lime is the Big Lime of west Texas.

It might be of interest to mention that in the Panhandle district the

Blaine gypsum formation caps the salt series, although in west Texas part of the salt series overlies the Blaine gypsum.

THE WEST SIDE OF THE BASIN

On the west side, in the vicinity of the Delaware Mountains, the Permian has been divided into the Delaware, Castile, Rustler, and Capitan formations.

The Delaware formation is a dark carbonaceous sandy limestone ranging from 2,000 to 4,000 feet thick. It is marine.

The Castile formation is composed of 2,000 or more feet of anhydrite and gypsum, resting apparently conformably upon the Delaware formation, the contact being a 30-foot bed of brown sandstone.

The Rustler formation is a thin dolomitic limestone bed about 200 feet thick, occurring at the top of the Castile.

The Capitan formation consists of 2,000 feet or more of dolomitic limestone, which also appears to lie conformably upon the Delaware formation. It outcrops in the mountains west of the area underlain by the Castile gypsum, and has been correlated with the Castile by most of the petroleum geologists who have studied the Trans-Pecos area.

In New Mexico, in the Artesia field, the stratigraphic section of the Permian, as shown by cuttings from the wells drilled in the field, is as follows: approximately 2,000 feet of gypsum and anhydrite containing red clastic material and some dolomitic limestone, below which the section is light and dark sandy dolomitic limestone. South of the Artesia field, in the Guadalupe Mountains, the Permian stratigraphic column has been subdivided into the Delaware, the Capitan, and the Carlsbad limestone.

On the southwest side of the basin, in the Glass Mountains, the following subdivisions have been made, from bottom to top: Wolfcamp, Hess, Leonard, Word, Vidrio, Gilliam, and Tessey. These formations consist for the most part of dolomitic limestone, containing sandstone and shale. The formations are fossiliferous and appear to be marine deposits throughout. They have a total thickness of about 7,000 feet.

CORRELATION OF THE BIG LIME WITH THE WEST SIDE

On paleontological evidence the Word formation of the Glass Mountains section has been correlated with the Delaware formation of the Trans-Pecos region.[1] Both are considered to be of Double Mountain

[1] J. A. Udden, "Notes on the Geology of the Glass Mountains," *University of Texas Bulletin No. 1753* (1920), p. 50.

age. Lithologically, they are somewhat similar. The Word formation is overlain by the Vidrio, which very closely resembles the Capitan of the Trans-Pecos region. They probably are to be correlated.

The correlation of southeastern New Mexico with the Trans-Pecos area and the Glass Mountains is still a moot question. Inasmuch as it may eventually furnish the key to the problem of the correlation of the Big Lime of the basin with the section on the west side, it is relevant to this paper.

In this paper it will be impossible to discuss all of the ideas which are being advanced regarding the correlation of the Permian strata on the west side of the basin. Some of the conflicting views and the various arguments given in support of them may be summarized as follows:

1. *The Big Lime, the Delaware, the Word, and the Artesia "pay" correlate.*

a) All of these formations are of Double Mountain age. This correlation is based on fossil evidence and subsurface correlation.

b) An extension of the strike of the contours of the Delaware formation from Texas into the Artesia field causes them to coincide with the contours on the pay zone of the latter. If the two do not correlate, a fold or fault of considerable magnitude would be necessary to explain the discrepancy.

c) These formations are similar lithologically, containing beds of bentonite near the top, and beds of dark sandy limestone. Such differences in lithology as are present may be explained by changes of facies. The correlation of the Delaware and the Word appears to be acceptable to all, although the difference in lithology between these two is about as great as between the Delaware and the Big Lime.

d) Within the basin, the contact between the lime series and the overlying salt and anhydrite series should be used as a time equivalent, because of the genetic significance of the two types of deposits.

2. *The Big Lime and the Artesia pay are above the Delaware and Word formations. They correlate with the Capitan formation, and with part of the anhydrite and salt series.*

a) West Texas may not have been one salt basin, but two or more during the Permian, and the Big Lime of one locality may correlate with the salt and gypsum of another.

b) The most concentrated salt solution may have settled into the deeper parts of the Permian basin, precipitating salt and anhydrite, while dolomitic lime was being deposited contemporaneously in the shallower portions of the sea.

c) Salt and anhydrite may have been precipitated in the shallowest parts of the Permian sea, where evaporation may have been greatest, while dolomitic lime was being deposited contemporaneously in the deeper portions, subsidence keeping pace with deposition.

d) Samples taken from drilling wells indicate that the Big Lime of west Texas and of New Mexico bears a closer resemblance to the Capitan than to the Delaware formation.

3. *The Big Lime of west Texas and of New Mexico correlate with the Capitan, being above the Delaware formation and below the Castile gypsum.*

a) The Castile lies unconformably upon the Delaware.

b) The Castile lies unconformably upon the Capitan.

c) Samples from the wells show that the Big Lime resembles the Capitan and not the Delaware.

d) Where the Castile gypsum directly overlies the Delaware formation, the Big Lime series has been removed by erosion.

CONCLUSION

These are only some of the current opinions which are in active circulation concerning the correlation of the Big Lime series with the type sections on the west side of the basin. The writer at the present time favors the first hypothesis, but realizes that more information is needed before a final correlation can be made. As in all current discussions about west Texas, the conclusion is that more drilling must be done before a final correlation of the west side of the basin can be made.

A SUGGESTED EXPLANATION FOR THE SURFACE SUBSIDENCE IN THE GOOSE CREEK OIL AND GAS FIELD, TEXAS[1]

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ABSTRACT

The conditions of the subsidence as set forth in a published report are considered briefly. The removal of oil, gas, and water is regarded as the cause of the subsidence, but the explanations given as to the mechanism of the subsidence are not considered satisfactory. The hypothesis is advanced that the oil, gas, and water occupied space in addition to the normal pore-space of the sands, and that their removal created cavities which were the direct cause of the subsidence. Conditions necessary for the presence of oil, gas, and water under the hypothetical conditions are considered. Features of the subsidence consistent with the hypothesis, and possibly related phenomena, are discussed, as is also the possible extension of the hypothesis to other fields.

STATEMENT OF THE CONDITIONS OF THE SUBSIDENCE

A paper recently published by Pratt and Johnson[3] gives a very interesting summary of the facts connected with the subsidence of the surface of the Goose Creek oil and gas field.

The field is on the shore of San Jacinto Bay, an indentation at the northwest side of Galveston Bay. The first recorded production was in 1912, and the total production to the end of 1916 was less than 1,000,000 barrels. The main sands, from 3,000 feet to 3,700 feet in depth, were discovered in 1917 and 1918, and a rapid development followed, during which millions of barrels of oil were removed from the field.

The section encountered in drilling consists of unconsolidated sands and clays of Oligocene to Recent age. Commercial production comes from depths of 1,000, 1,500, 1,700, 2,000, 2,400, 2,600, 3,000, 3,700, and 4,100 feet. Centrally located wells have been drilled to depths greater than 5,000 feet without encountering any characteristic salt-dome materials.

[1] Read before the Association at the Tulsa meeting, March 26, 1927. Published by permission of Henry L. Doherty & Company.

[2] Consulting geologist, Henry L. Doherty & Company.

[3] Wallace E. Pratt and Douglas W. Johnson, *Jour. Geol.*, Vol. 34, No. 7, Part I (October–November, 1926), pp. 577–90.

In 1918 the surface of the field began to subside and Gaillard Peninsula and other low-lying lands in the field were submerged beneath the waters of San Jacinto Bay. The subsidence was continuing late in 1925. By this time the subsidence had reached a maximum of $3\frac{1}{4}$ feet near the center of the field (the area of maximum extraction), grading to zero at the edges of the field.

The authors of the paper consider the possible causes of the phenomenon and decide that the subsidence is not connected with any regional change in sea-level, but that it is purely local; also, that the exact coincidence of the subsiding area with the area from which oil and gas were extracted, and of the time of the subsidence with the time of extraction, is complete proof that the subsidence was caused by the extraction of the oil and gas, and the water and sand which were produced with them. They point out that the volume of material sinking at the surface, that is, the volume between the original surface and the surface late in 1925, was equal to only 20 per cent of the estimated volume of gas (calculated at 1,000 pounds per square inch pressure), oil, water, and sand which had been removed. With these conclusions of the authors there can be no disagreement.

However, the present writer has found considerable difficulty in attempting to visualize the exact processes of the subsidence in the light of his previously held ideas as to the oil, gas, and water being confined to the pore-space in the sands.

SUGGESTED CAUSES OF THE SUBSIDENCE

Pratt and Johnson make the following suggestions as to the causes of the subsidence (reworded and arranged by the present writer).

1. Removal of sand.
2. The reduction of moisture content in the clays by escaping gas.
3. The reduction of pressure in the reservoir sands from 1,000 or 1,200 pounds per square inch to atmospheric pressure, permitting water to drain from the adjoining clays and thus compacting them.

To these may be added the possibility of the solution of bodies of salt or other soluble solid material which Pratt and Johnson rule out from consideration because no known quantities of such materials have been encountered in drilling to depths of 1,000 feet below the deepest producing horizon.

REMOVAL OF SAND AS A CAUSE FOR THE SUBSIDENCE

The first suggestion, the removal of sand, may be considered very briefly. Any quantity of sand produced by the wells in this field almost

certainly would be deposited near the well mouth and remain there during any such period of time as is under consideration. Such sand would occupy as much room at the surface as it did underground, and there could be no surface subsidence. It is very difficult to conceive of sufficient quantities of sand being produced and carried entirely beyond the boundaries of the area in question to have any appreciable effect in causing the subsidence, although it may account for a small part of it.

THE EXTRACTION OF WATER FROM THE CLAYS AS A CAUSE OF THE SUBSIDENCE

The efficiency of the two remaining suggestions depends on the properties of clays and the conditions in regard to moisture throughout the entire system. The following general points should be noted.

The maximum subsidence to be accounted for in 1925 was $3\frac{1}{4}$ feet. The subsidence was continuing, so that the ultimate subsidence is still in doubt. There is also the question as to whether the filling of cavities at depths of 1,000 to 4,100 feet by collapse of the overlying material, even in unconsolidated rocks, would not be partially compensated by adjustments in these overlying beds, so that it would not show at the surface as 100 per cent of the total shortening of the rock column. It probably would be safe to add 50 to 100 per cent to the observed shortening to take care of additional subsidence and of the adjustments between the depths of disturbance and the surface, giving a total shortening of, say, 6 feet, although it might be slightly less or considerably more.

The linear drying shrinkage of a clay sufficiently wet to be easily shaped by the fingers varies from nearly zero for sandy clays to 12 or 13 per cent for ordinary plastic, fine-grained clays. The shortening of the rock column at the center of the field is the drying shrinkage from a highly plastic condition to complete dryness of a bed of clay about 50 feet thick.

The existence of clay at depths of 1,000 to 4,100 feet, so plastic as to have such high shrinkage, seems improbable at first thought, and more so when it is considered that such clay would be deformed at very small pressures and should flow easily and rapidly into the holes as the wells were drilled. The idea of drying the clays, at such depths and with water conditions such as are present in most oil fields, until a stage is reached corresponding to air-dried clay, also seems untenable. If we can imagine the drying process to proceed to the extent of a $12\frac{1}{2}$ per cent linear drying shrinkage, the shortening of a bed of clay across the length of the field ($2\frac{1}{2}$ miles) would be about $\frac{1}{3}$ mile which would be accommodated only by the formation of cracks, which would tend to destroy the reservoir

effect of the sand lenses. If the clay retained sufficient plasticity to adjust itself by flowage to the shrinking along its vertical and lateral dimensions, we would certainly expect no greater linear drying shrinkage than 5 per cent, which is still the total linear drying shrinkage of many fairly plastic clays. This drying-shrinkage factor would require the drying and compacting of an original thickness of 120 feet of clay to account for the assumed maximum shortening of the rock column to the extent of 6 feet, considering only the vertical shortening. If there were interior movement to accommodate the lateral shortening, that is, if the clay continued plastic enough to flow under the pressures, so that no cracks were formed, the vertical shortening would be greater, since the entire shrinkage would be compensated by the vertical shortening, and the thickness of the clay to be dried to produce the shortening would be less. This condition presupposes a very plastic clay to be deformed at the pressures in the shallower horizons, and drying could not be supposed to proceed very far. Such an adjustment would also tend to make the vertical shortening and the subsidence equal over the field, and probably to extend beyond the productive area.

One factor which may invalidate, to some extent, the reasoning just given is the moisture content of the clay.

Pratt and Johnson[1] make the statement that "the clays and gumbos carry as much as 30 per cent (by weight) of moisture, whereas ordinary clays or shales of Cretaceous age in the Gulf region carry only 10 per cent."

A moisture content of 30 per cent means that the clay considered in its dry state has absorbed 43 per cent of its own weight of water. Some years ago the present writer tested eighty-three samples of clay from Oklahoma and found that the highest percentage of water, in terms of the dry weight of the finely ground clay, required to develop working plasticity was 32.2 per cent, and the average percentage was 22.6 per cent. The clays would hold more water than this, of course, but a clay holding 43 per cent of its dry weight of water would certainly be very plastic and most probably a very soft "mucky" clay or mud. It would be interesting to know the source and the conditions of sampling of the clays and gumbos which showed a moisture content of 30 per cent of their wet weight.

If the majority of the clays associated with the producing sands at Goose Creek contain 30 per cent by weight of moisture, the linear shrinkage on partial drying might be somewhat greater than the 5 per cent here estimated.

[1] *Op. cit.*, p. 583.

It would seem, however, that a clay with this percentage of moisture would flow under pressure of the overlying beds so readily as to make even rotary drilling very difficult. While it is impossible to give even approximately definite answer to the question of the thickness of clay which would have to be drained to give the compacting necessary to account for the observed subsidence, a consideration of the conditions seems to point to the fact that this thickness must be a considerable number of feet, and that even when the total thickness affected is distributed among the many producing sand horizons, it will be of very substantial dimensions and measured in feet for each of them.

To accomplish the draining of water from the shales to permit the compacting necessary to account for the subsidence, Pratt and Johnson suggest two methods: (1) The evaporation of water from the shales by expanding gas, and (2) the drainage of water from the surrounding clays into the sand lenses in which the pressure has been reduced.

THE DRYING OF THE CLAYS BY EXPANDING GAS

The drying of the clays by expanding gas could occur in two places: one at the boundary of the gas reservoir sand with the surrounding clay, and the other at the surface of the clay beds in the uncased portion of the wells.

While there are no data available on the subject, so far as the writer knows, it does not appear reasonable that there would be enough gas in actual contact with the clay in the reservoir, nor that its expansion in that position would be sufficient to produce any appreciable drying. The pore-space area of the sand at the clay contact will be small, and the greater part of the expansion certainly would take place in the well and in the sand reservoir at some distance from the surrounding clay. The area of clay exposed in the walls of the wells is undoubtedly small, and there is a good chance that water was being sprayed on the exposed walls rather than being evaporated from them. It would seem, therefore, that there is very little probability of the expanding gas evaporating enough water from the clay to dry any appreciable part of the mass of clay which must be dried to produce the compacting necessary to bring about the subsidence at the surface.

THE SQUEEZING OF WATER FROM CLAYS BY PRESSURE

The drainage of water from the clay surrounding the sand lenses, due to the reduction of the pressure in the sand, and the forcing of water from the clay to the sand by the unbalanced pressure of the rock column is the remaining suggestion as to the cause of the compacting of the clay.

Clay retains water very tenaciously. It is difficult to press water even from a wet mud, and it is very doubtful that the pressures involved would do it.

The pressures are not extreme. The weight of moist sands and clays averages about 100 pounds per cubic foot. Estimating this at 110 pounds gives a rock pressure of practically 770 pounds per square inch for 1,000 feet of depth. The deepest productive sand would, therefore, have a rock pressure of approximately 3,000 pounds per square inch, while the 1,000-foot sand should have a rock pressure of not more than 770 pounds, on the assumption of no competency whatever in the strata.

It is very much to be doubted if such pressures, especially the lower ones, would squeeze much water from clays, except possibly from super-saturated sandy clays, and sandy clays would not have the plasticity, shrinkage, or high moisture content which the theory and the conditions seem to demand.

Another feature which should be noticed is that the contact between the clays and sands would resemble that in a filter press. The first action would be the forcing of some of the wet, soft clay into the pores of the adjacent sand, thus tending to clog them. If we grant any squeezing of water from the clay next to the sands, the result would be to form a thin compact layer of clay over the surface of the sand, which should be highly impervious and an efficient barrier against any movement of water from farther back in the clay.

These opinions are the writer's own. They are checked in large measure by the opinions of George H. Brown,[1] as follows:

1. Whether pressures of 1,000 or even 2,000 lbs. per sq. in. would squeeze water from a plastic shale would depend altogether upon the plasticity of the shale. If the shale were deficient in plasticity—in other words, a very lean one—I believe the high pressure would result in squeezing out the water. However, a normally plastic shale under these conditions would not lose its water, but the shale itself would be forced into the interstices of the sand.

2. In the case of very lean clays and shales I have noticed a separation of the water under high pressures. However, if normally plastic shales are subjected to high pressures in an auger machine the clay itself is forced out through the joints and openings in the machine.

3. Whether a clay containing 30 per cent of water would be so plastic as to be deformed by very slight pressures would again depend altogether upon the plasticity of the clay. It has been my experience that the water of plasticity of shales and clays on the dry basis will range all the way from 20 per cent in the case of lean clays up to 40 per cent in the case of highly plastic clays. Here

[1] Director, department of Ceramics, Rutgers University. Personal communication.

again if the clay were in the soft plastic condition the water would not be squeezed out by high pressures, but the clay itself would flow into the holes when the wells were drilled.

Thirty per cent of water would be sufficient to convert some clays to the soft mud condition and others only to the stiff plastic condition.

If it be assumed that the clay compacted sufficiently to cause the subsidence, it must be given a high plasticity to have the necessary shrinkage, and such clay would probably not give up water under pressure, certainly not under the pressures of the shallower sands, and the disturbance of the original conditions in the shallower sands must have originated the subsidence, judging from the time of development of these sands and the date of beginning of the subsidence. If clays so lean as to yield water at such pressures be assumed, the shrinkage would be very low, and an almost unbelievably great thickness of the clay must be drained to produce the subsidence. Clays are generally lean because they are slaty or sandy. Slaty clays may be ruled out of consideration in the present case, and clays so sandy as to yield water on pressure would be very doubtful barriers to the migration of oil and gas.

Even if we assume the possibility of pressing water from plastic clay, there is still another feature to be explained. If the subsidence is due to the compacting of the clay by drainage of water into the sands, in which the pressure has been reduced, the subsidence should be more nearly uniform over the field and not a maximum near the center fading out to the edge. It appears reasonable that the pressure would be reduced more or less evenly over the field, and that any inequalities would be compensated by the flow of clay to the areas of lower pressure, if the clay were sufficiently wet to give up water under pressure. There should thus be a nearly equal compacting of the clays over the producing area, and consequently a more nearly equal subsidence over the area of the field, and the subsidence would probably extend beyond the producing area.

The considerations given above make it very difficult to accept the idea that the extraction of water from the clays, either by evaporation, by expanding gas, or by pressure, has permitted sufficient compacting of the clays to account for the subsidence at the surface.

THE POSSIBILITY OF SUPPORT OF THE SURFACE BY OIL, GAS, OR WATER

As an alternative hypothesis it is suggested that the oil, gas, and, possibly, the water occupied space in addition to the pore-space of the compact sands, that is, that they occurred as thin layers, or beds, or

pimple-like bodies above the sands for which state we may use the term "free" oil or gas; or that the oil or water held the grains apart as water is known to do in quicksand. The possible mixture of sand and oil in this condition may be referred to as oil quicksand. The writer has found no references in the literature to the supposed occurrence of "free" oil, but it is interesting to note that the possibility of the oil quicksand is suggested by A. Beeby Thompson[1] as follows:

> Mr. B. Thompson, in calling the author's attention to the above notes [on the porosity of sands] remarks that the capacity of the Baku oil sands must have been enormously increased if, as seems probable, immense quantities of organic remains were buried with the sands, as the capacity of the sand bed would be greater than sand with natural interspaces by the amount of space these organisms occupied before being sealed up, and before complete decomposition, i.e., whilst they were in part solid. No amount of pressure subsequently applied would greatly diminish this capacity, owing to the gas pressure, which, within certain limits, increased as the pressure of the over-strata increased. It is quite possible that the original presence of much organic matter affords an explanation of the huge capacity of some oil sands, greatly exceeding the maximum normal capacity for any fluid; and whilst agreeing with the theory of the origin of oil advocated, it offers a simpler explanation of some of the physical phenomena described, such as the easy movement or flow of sand.

It is evident that this picture of the condition of the oil sand is that which the present writer is calling oil quicksand; he believes that other explanations of its origin may be developed, and at the same time regards the foregoing explanation as a possibility. The presence of oil quicksand would be of great assistance in explaining the wonderful productivity of the Baku fields and the extraordinary mobility of the productive sands.

The existence of "free" oil or gas, or of oil quicksand, requires that the material forming the oil and gas was originally present in the sands, or that the oil and gas were introduced into the system under an impervious layer, and with sufficient pressure to overbalance the effective weight of the superincumbent strata. This effective weight need not be the total weight of the rock column, since part of this weight may be supported by competent beds.

Since the oil and gas may have been introduced into the system at, or very shortly after, the time the containing beds were deposited, the rock column lifted and supported by the oil, gas, or water need not be the present column, but one much less. Any process of sealing around the oil and gas deposit, by increased hydrostatic head, by compacting, by

[1] *Oil Fields of Russia,* note on chapter B, p. 104.

cementation,[1] or by depositional or structural barriers would permit the accumulation to remain in spite of additional loading. The pressures developed in the accumulation should increase ratably with the additional loading unless the additional load was supported in part by competent beds above the accumulation, or unless there was slow leakage from the reservoir.

The pressure at which the oil, gas, or water was introduced into the system to produce such an accumulation would have to lie between that necessary to support the overlying beds and that necessary to rupture them, which is probably a considerable range. Concerning the pressures, it should be noticed that, if there are discrete layers of oil or gas, particularly of the latter, the pressure would drop very rapidly when the reservoir was tapped. To know the portion of the rock column which the gas (or oil) pressure is capable of supporting, the original pressure in the undisturbed reservoir must be known, and this is seldom, if ever, obtained.

If gas or oil were introduced into, or formed in, sands at pressures sufficient to lift the rock column at the time of their forming or introduction, and were later more deeply buried, some of the gas or oil, or both, would be pressed out from its original position by the weight of the added rock column. If the sealing in of the deposit were not complete, the oil and gas might be pushed out for some distance and fill the interstices of the sand which were originally filled by water. This condition may account, in part, for such general accumulations as that in the Bartlesville sand in the Independence-Bartlesville-Tulsa area, where the sand is rather generally saturated both on and off of "favorable" structure.

The reverse of the conditions considered in the preceding paragraph is also possible. The gas and oil might be formed in, or introduced into, the sands at pressures insufficient to lift the rock column under which they were buried. Denudation might lighten the column until the pressures were sufficient to produce lifting and to permit a general rearrangement of the gas, oil, and water in the area.

SUPPORT OF THE SURFACE BY WATER

The power of water to support considerable weight of overlying rocks seems to be fairly well substantiated.

Veatch[2] investigated the fluctuations of water level in wells on Long Island and found that these fluctuations were in part tidal and that the

[1] See description of Nacatoch sand in the Smackover field by H. G. Schneider, *Trans. A.I.M.E.*, Vol. 70 (1924), p. 1083.

[2] A. C. Veatch, *U. S. Geol. Survey Water-Supply Paper No. 155*, 1906.

tidal fluctuation affected wells on Long Island as deep as 386 feet, and refers to other wells as deep as 925 feet where the same effect has been observed. He concludes[1] that tidal fluctuations are produced in three ways:

1. By transmission of pressure through open cavities or passageways affording a free communication between the wells and the ocean;

2. By a checking of the rate of discharge through porous beds freely connecting with the ocean; and

3. By a deformation of the strata due to the alternate loading and unloading of the tides.

In the last case, instead of leakage being an important factor, as it is in the first two, the fluctuations are greater the more nearly complete the separation of the oceanic and ground waters.

It is only the wells of the third class in which we are interested, and Veatch's conclusions[2] in regard to those wells are quoted:

TIDAL FLUCTUATIONS IN WELLS PRODUCED BY PLASTIC DEFORMATION

Besides the shallow wells, depending on ordinary porous surficial beds, there are, along and near the seacoast, many deep artesian wells which show tidal fluctuations. In many of these wells there are clearly no underground caverns involved, the water-bearing beds being ordinary porous strata in which the water flows through the small interstices at a rate to be expressed in feet rather than miles per day, and in which accumulation or depletion by simple flowage will be correspondingly slow. There is, moreover, every reason to believe, in some cases where there are thick clay beds above the water-bearing strata, which are known to be continuous for many miles, that there are no near sub-oceanic outlets of importance. In case there is some distant outlet it is evident from the slow rate of change shown in the examples given above, where there was a sudden increase or decrease in the volume of river water, that the fluctuation produced by a simple checking or hastening of the rate of outflow could be propagated but a short distance, and that a long period of time would be necessary for even that.

There is, however, in the case of waters under artesian head a new factor introduced which is of very great importance. The pressure of the artesian water exerted against the retaining cover, which may be assumed at present to be clay, tends to elevate it, thus placing the clay under an upward stress. The addition of any weight on the surface tends to disturb the equilibrium. If there is no outlet and the weight is applied uniformly, the additional weight cannot change the position of any portion of the mass, except to the very slight degree of the elastic compressibility of the water and the soil. If, however, there is any escape for the confined water, such as would be afforded by a well tube, the

[1] *Op. cit.*, p. 63. [2] *Op. cit.*, pp. 65–66.

mass will yield and the water be forced up in the tube. Were the clay layer perfectly elastic, or in the condition of a stretched elastic membrane above a perfectly mobile body, there would be no time lag, and the water in the well would exactly follow the fluctuations of the ocean waters; but the clay is not to be regarded as an elastic diaphragm, and the water-bearing sand is not a perfectly mobile body; moreover, for such a deformation to be felt in a well water must be transferred from one point to another, and this involves a time element. The deformation is essentially a plastic one; the clay yields to the superposed weight and the water is lifted in the well, but if there were no pressure from below the clay could not return to its original position. In the case of tides along the coast only the portion of the clay layer under the ocean is loaded, and that loading is a progressive one from a distant point toward the shore. The effect is a deformation in which the clay layer is depressed under the ocean and elevated under the land. When the weight is removed the artesian pressure tends to re-establish the old conditions of equilibrium, and the clay layer is lifted under the ocean and sinks under the land.

If the artesian pressure is high, compared with the tide when the ocean water commences to fall after high tide, this pressure lifts the clay quickly and thus tends to shorten the high-tide lag in a near-by well; as the tide falls the high pressure enables the clay to follow the tide closely; at low tide the artesian pressure is clearly in the ascendancy and the clay still rising in the ocean area. As the tide begins to rise it must overcome this artesian pressure before any deformation occurs, and the rising curve in the well therefore lags more behind the tides than the falling curve. Under such conditions the high-tide lag is less than the low-tide lag. Conversely, when the artesian pressure is low compared with the tide, at high tide the feeble artesian pressure but slowly lifts the clay weight and the lag is long; at low tide, when the clay diaphragm is high, the greater tidal weight quickly overcomes the feeble resistance of the artesian water and the lag is short; it may then happen that the low-tide lag will be less than the high-tide lag. It is evident that between the two extremes thus indicated there are all possible variations, and that the thickness and plasticity of the beds above the water-bearing layers are important modifying factors. The fluctuation in a well in such cases does not furnish an exact measure of the amount of deformation; it furnishes only a fair indication of the variation in pressure at the particular point at which the well is sunk.

The maximum effect is felt at the seacoast near low-tide mark and gradually decreases inward, disappearing in a few miles. It is less if there is leakage from sub-ocean springs, for in such cases the escape of the water decreases that available for the elevation of the water in the tube. In many cases springs near the coast, deriving their supply from the water beneath the clay, are likewise tidal. The cause of this phenomenon in the Bridlington Quay wells, Yorkshire, was correctly given by Inglis in 1817. He recognized in the clay layer a moving diaphragm affected by the tidal pressure from above and the artesian pressure from below.

It seems evident that there must be water in excess of that held in the pore-space of the sand to produce the lifting effect on the overlying clay, to which Veatch attributes the tidal fluctuation of the water level in the wells. Veatch also describes the fluctuations of level in shallow wells produced by showers and concludes that these fluctuations are produced principally by the loading of the surface by the weight of the fallen water, acting through the air entrapped in the soil in some cases, but through action of the clay diaphragm where such is present above the water sand.

Meinzer and Hard,[1] from a study of the rates of discharge and recharge, and the readjustment of the hydraulic gradient in the Dakota sandstone in North Dakota, conclude that part of the water produced in the thirty-eight years previous to 1925 was stored in the upper layer of the Dakota sandstone and has not been replaced by percolation; that this storage was due to a volume elasticity of the sandstone; that nearly half of the pressure of the beds overlying the Dakota was supported by the water at Ellendale, where the depth to the Dakota is 1,035 feet and the original artesian head was 333 feet at the surface; that if at any point within the area of artesian flow the head at the surface was as great as the depth to the Dakota sandstone, the artesian pressure must have been great enough virtually to float the overlying beds; that the stored water in the Dakota under the area considered probably was equivalent to a layer of water 4.4 inches thick over the area; and that the upper part of the Dakota sandstone may have been compressed to the extent of a few inches.

The present writer can see little difference in the effect on a possible surface subsidence, of a layer of water a few inches thick on top of a compact sand, and water which holds the grains of sand apart so that a compacting of the same amount results when the water is removed. In the case of oil under similar pressure conditions, the sand would probably settle and some of the oil collect as a layer on top of the saturated sand, although with heavy oils a condition analogous to quicksand might exist.

FEATURES OF THE SUBSIDENCE FAVORING THE SUPPORT OF THE SURFACE BY OIL AND GAS

Two features of the subsidence at Goose Creek which seem to favor the idea of the support of the surface by the oil and gas are:

[1] Oscar E. Meinzer and Herbert A. Hard, "The Artesian Water Supply of the Dakota Sandstone in North Dakota," *U. S. Geol. Survey, Water Supply Paper, No. 520-E* (1925), pp. 90–93.

1. The maximum subsidence is in the central part of the field, where there was the maximum production of oil and gas. In many fields as much or more water is produced from the edge leases as from those in the center of the field, although the writer is informed[1] that the maximum water production at Goose Creek came from the center of the field. The conical shape of the depression at the surface is suggestive of the result of removing material in the center of the field, since it is of the same shape as the surface developed in a bin or hopper of unconsolidated material by removal of the material at the center of the bottom of the bin.

2. The active development of the field began in 1917 and the subsidence was noted in 1918. There was probably some lag between the removal of the material and the appearance of the surface subsidence, so that the subsidence, at least in part, is due to the removal of material very early in the history of the field, when only the sands shallower than 3,000 feet were being developed.[2]

In the 1,000-foot sand, oil and gas under a pressure of about 770 pounds per square inch would be capable of supporting the surface even if all the weight of the superincumbent beds were effective, and under a pressure of 1,200 pounds per square inch would be nearly or quite capable of doing so in the 1,500 and 1,700-foot sands. The maximum recorded pressure of 1,800 pounds[3] would support a rock column of nearly 2,400 feet, although this pressure was probably in a deeper sand. There is always the question of whether the recorded pressures are the maximum pressures in the undisturbed reservoir, and also as to the portion of the weight of the rock column which may be supported by competent beds.

POSSIBLY RELATED PHENOMENA

So far as the writer knows, there is no other recorded case of the surface of an entire field subsiding on the removal of the oil and gas. It is apparent, however, that the small subsidences might occur in many fields and escape detection. The subsidence at Goose Creek was made manifest at an early stage on account of its location on the shore of Galveston Bay. Slight changes of level, even if accompanied by faulting of a few inches displacement, would probably pass unnoticed in most oil fields.

The formation of craters such as those in the Smackover field may be,

[1] Personal communication from Wallace E. Pratt, March 12, 1927.

[2] The dates of discovery of the different sands are given in a personal communication from Wallace E. Pratt as follows: 1,600-foot sand in 1908; 2,000-foot sand in 1916; main sands from 3,000 to 3,700 feet in 1917 and 1918; deeper sands in 1922.

[3] Wallace E. Pratt, personal communication.

however, a closely related phenomenon. While the craters are ordinarily spoken of as "blow-outs," it is evident that only a very small part of the material is blown out of the crater, and that practically all of it sinks into the ground. The amount of material which has disappeared below the surface is enormous, and certainly implies the formation of large open spaces underground. Although these spaces cannot be said with certainty to have been produced in the oil and gas horizons, it is very difficult to see how they could be produced at higher levels. It seems reasonable to assume, in the absence of evidence to the contrary, that these spaces were produced in the vicinity of the maximum disturbance of the original conditions, which would be in the producing sands. The craters are straight-walled and are more suggestive of formation by collapse of a portion of a roof over a cavity than they are of the removal of material from the center of the bottom of a bin of unconsolidated material.

So far as the writer knows them, the recorded pressures in the Smackover field are not sufficient to support the weight of the entire rock column above the producing sands, but the true initial pressures of the wells which cratered are unknown, and there is undoubtedly considerable competency in the overlying rocks.

The abnormal yields of certain wells or tracts would be explained easily by the hypothesis of the presence of oil and gas in the "free" state, or of oil quicksand, and this explanation appears as logical to the writer as any others which have been advanced. Some of these phenomenal yields may be noticed briefly:

The Lakeview gusher at Maricopa, California, is estimated to have produced 9,000,000 barrels of oil in eighteen months before it sanded up. This is equivalent to a layer of oil 116 feet thick over 10 acres, or to a 100 per cent recovery over 10 acres from a completely oil-saturated sand of 30 per cent porosity and 387 feet thick. The Union Oil Company's Hartnell No. 1 in the Santa Maria field produced 3,000,000 barrels before being placed on the pump, a production one-third as great as the Lakeview well.

The ultimate production of a 55-acre tract in the West Columbia field in Texas is estimated by Barton[1] at 300,000 barrels per acre, and of a two-acre tract at about 975,000 barrels per acre, equivalent respectively to layers of oil 48 and 125 feet thick. One 120-acre leasehold in the Elbing field in Kansas has produced 40,000 barrels per acre, equivalent to a layer of oil more than 5 feet thick. The maximum sand penetration of the wells—neglecting one deep-sand test—is 21 feet, and the average pene-

[1] Donald C. Barton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), p. 245.

tration is 11 feet. The recovery to 1927 is equivalent to a 100 per cent recovery from a completely oil-saturated sand of 50 per cent porosity of the same thickness as the average sand penetration. The well with the largest initial production has a sand penetration of only 6 feet, and was completed 3 months later than the discovery well on the lease.

In restating these productions in terms of the thickness of an equivalent layer of oil, it should by no means be inferred that the writer visualizes layers of "free" oil underground of any such thickness.

Drainage from adjoining lands certainly accounts in part for such phenomenal yields, but the possibility of free bodies or streaks of oil, or of oil quicksand, would render the explanation easier.

The occasional finding of exceptional gusher wells near previously drilled smaller wells would also be more easily explained by this hypothesis, although other explanations are, of course, possible.

POSSIBILITY OF FREE OIL OR GAS AND OIL QUICKSAND IN HARD-ROCK FIELDS

It is scarcely conceivable that oil or gas could be introduced into a series of consolidated, cemented beds under sufficient pressure to disrupt the sands and form an oil quicksand or to lift the overlying shales. However, we have little or no knowledge as to the time of introduction of the oil and gas and the conditions of the rocks at the time they were introduced; nor indeed do we have very accurate knowledge of the exact character of the producing rocks as they are now. It is well known that the best production from hard sands is generally found in soft pay streaks in the sand. The writer has always considered that these pay streaks are good oil sands because they are uncemented, but has been unable to give any good reason why they may not be uncemented because they *were* good oil sands.

The experimental and mathematical possibility of the formation of anticlinal structure by the pressure of oil was investigated by McCoy[1] in 1915, and the subject was discussed at that time.

The lack of surface subsidence in hard-rock fields is not proof that the oil and gas did not occupy space in the sense of this paper, on account of the competent beds overlying the oil sands. Repair work on old wells in moderately hard sands often shows the development of considerable cavities at the foot of the well. The removal of sand during the earlier operation certainly accounts for part of these cavities, but not certainly for all of it, so far as our knowledge goes.

[1] A. W. McCoy, *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), pp. 140–47.

The common reports of large initial productions, with the sand merely scratched, are suggestive of highly abnormal conditions at the top of the sand, and the very sudden increases in production at different distances in the sand are worthy of consideration in this connection.

POSSIBILITY OF "FREE" OIL OR GAS BEING UNNOTICED IN DRILLING

The lack of recognition of bodies of "free" oil or gas in drilling is a valid objection to belief in their presence. However, such bodies, if they exist, will in most cases be under high pressure and also under a highly impervious cover. It is well known that the pressures of gas and oil when encountered under such conditions are often sufficient to float the drilling tools or even to blow them from the hole. The writer believes that with the lack of accurate measurements, and under the excitement naturally attending such situations, it is entirely possible that gas- or oil-field space of very appreciable dimensions might entirely escape detection and be reported as "sand."

SUMMARY

1. The removal of oil, gas, water, and sand from the Goose Creek field is accepted as the explanation for the subsidence of the surface.

2. The removal of sand is believed to be a very small factor in producing the subsidence, on account of the difficulty in removing the sand from the area of the field.

3. The drainage of water from the clays, either by the expansion of gas or by squeezing due to the release of pressure in the adjoining oil and gas sands, permitting a compacting of the clays, is believed to be ineffective. Either the clay must be so plastic as not to yield appreciable quantities of water under the conditions present, or so lean as not to give the shrinkage required to produce the surface subsidence.

4. The hypothesis that the oil, gas, and water occupied space in addition to the normal pore space of the sands is suggested. The oil, gas, or water would be present as discrete bodies or layers or, in the case of oil and water, in a quicksand, or in both conditions. Under some conditions it is thought possible for the oil, gas, and water to support the surface.

5. The conditions necessary for such occurrence are thought to be well within the range of probability.

6. The shape of the subsidence and the time of its initiation are believed to be consistent with ideas of the oil, gas, and water occupying space in addition to the normal pore space and of their having supported the overlying rock column.

7. Tidal fluctuations in wells near the seashore, and the artesian phenomena in the Dakota sandstone, are considered as evidence of the entire or partial support of the surface by water.

8. Cratering, the phenomenal rate of oil production of some wells, and the phenomenal ultimate production of certain tracts and wells are considered consistent with the hypothesis of oil and gas existing underground in the "free" state or of oil being present in oil quicksand.

9. The presence of gas in the "free" state and of oil in the "free" state or in oil quicksand in hard-rock fields is considered possible.

10. It is considered possible that gas or oil-filled space might escape detection in drilling on account of the high pressure existing at the horizons where such occurrences are probable.

SOME PROBLEMS OF THE CHUGWATER-SUNDANCE CONTACT IN THE BIGHORN DISTRICT OF WYOMING[1]

A. E. BRAINERD[2] AND I. A. KEYTE[3]
Colorado

ABSTRACT

This paper deals with the finding of a Sundance fauna in a horizon now included in the Chugwater formation. Suggestions are given for a new division and sections illustrate the conditions found.

During the summer of 1925 the senior author was making a regional study in the Big Horn region and noticed a persistent zone of thin limes, gypsum, and red shale at the top of the Chugwater formation. The limes in the several sections were examined for fossils, and on Pryor Mountain a good collection of fossils was taken from limes near the base of this zone, about 200 feet below the top of the Chugwater. This collection, which the authors considered to be of Sundance age, was sent to T. W. Stanton for identification and verification. Dr. Stanton pronounced the collection Sundance in age. These facts bring up the question of the areal extent and thickness of beds, which must be taken from the Chugwater formation of Triassic age and included in the Jurassic.

A set of sections from the Pryor Mountains, at the north end of the Big Horn ranges, to the Rattlesnake Mountains at Ervay, about 35 miles south of the southeast end of the Big Horn range and about 50 miles west of Casper, was made to show the relationships of the present Chugwater and Sundance contacts and the probable amount of the Chugwater, which should be included in the Sundance, or at least in the Jurassic.

This zone, which lies between lines A–A and B–B on the accompanying sections (Figs. 1 and 2), is the one in question, and it differs in many respects from the main body of the Chugwater.

The main body of the Chugwater consists of unbroken red shale, with an occasional bed of more resistant red sand, which forms the benches. This series is entirely of clastic sediment. These sediments are considered

[1] Read before the Association at the Tulsa meeting, March 26, 1927.

[2] 2333 Albion St., Denver, Colorado.

[3] 317 E. San Rafael, Colorado Springs, Colorado.

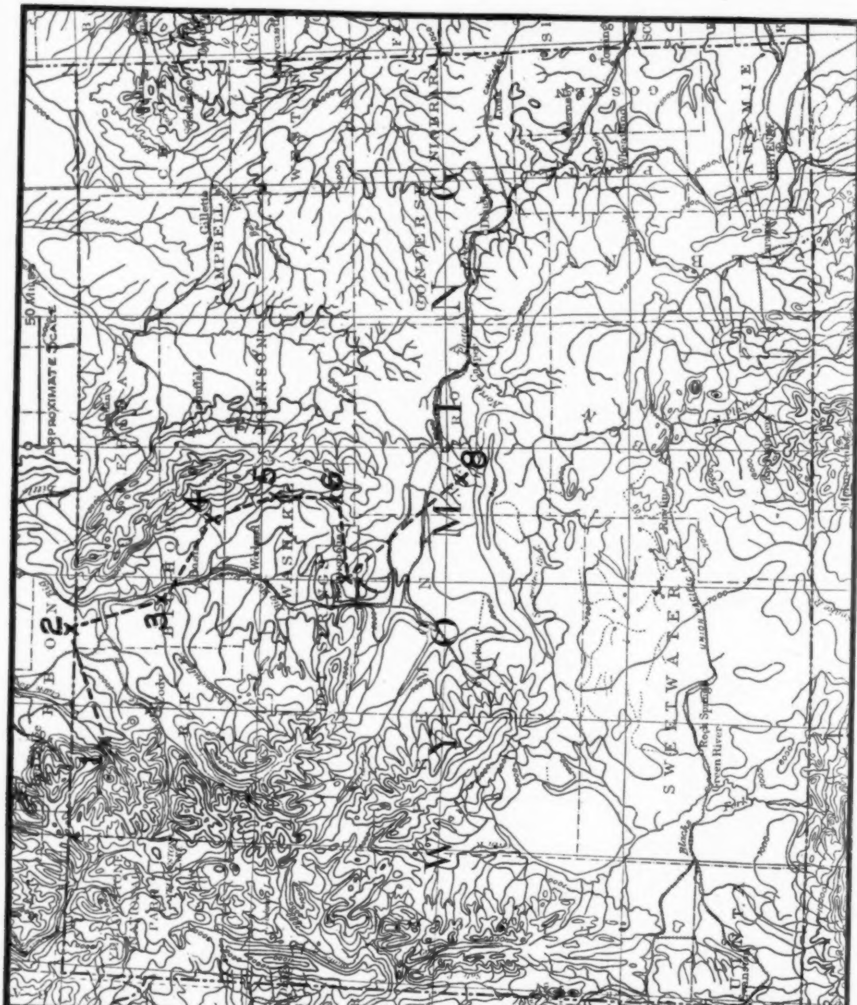

FIG. 1.—Map of Wyoming, showing geographic relation of sections shown in Figure 2. Contour interval, 1,000 feet

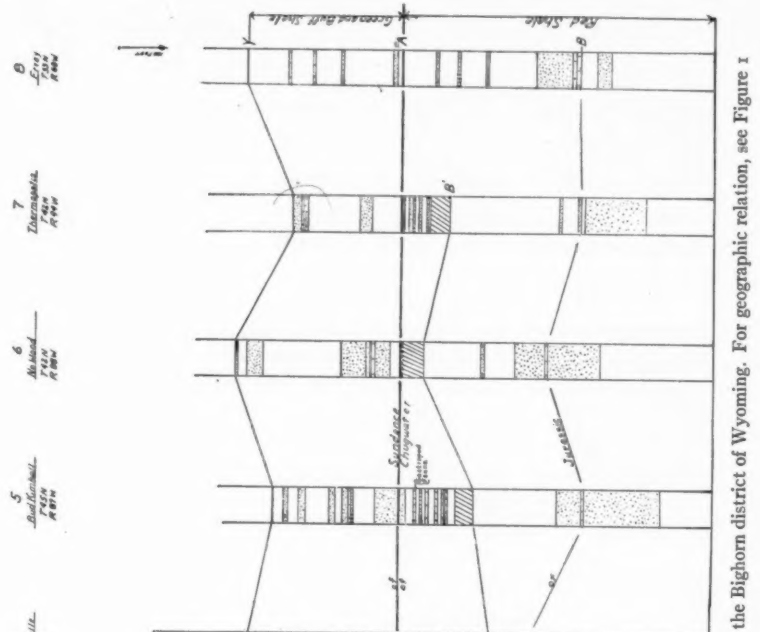

FIG. 2.—Sections showing Chugwater-Sundance contact in the Bighorn district of Wyoming. For geographic relation, see Figure 1

by Branson to be marine, with the exception of the Popo Agie beds, which he has proved to be non-marine.[1]

Certainly the upper part of the Chugwater, which includes the gypsum and thin limes and makes up the zone with which this paper is concerned, is of marine origin, and, as far as could be ascertained, there is no break between this zone and the main body of red sediments below.

This zone apparently thins from south to north; sections on the Rattlesnake Mountains show a thickness of about 400 feet, if our interpretation is correct, and sections on the Pryor Mountains show from 100 to 200 feet.

The thinning may be explained in two ways: (1) the original deposits were thinner toward the north, or (2) an erosion period existed between the deposition of this zone and the deposition of the green and buff shales of the Sundance. A seeming unconformity along line A–A of the sections, or between the green and buff shales of the Sundance and the lime gypsum zone, indicates that such an erosion period did exist. While no single section which was measured shows this unconformity, the varying contact materials over wider areas indicate it, and then, too, we know that as these pass northward in Montana, the Sundance, or Ellis, overlaps the Chugwater and Quadrant and lies on the Madison lime, of Mississippian age. This places the unconformity in the Jurassic in this region, and not between Jurassic and Triassic.

Two suggestions are offered as to the base of the lime and gypsum zone, which evidently belongs in the Jurassic. These are illustrated on the sections by lines B–B′ and B–B. Line B–B′ is drawn at, or just below, the base of the gypsum beds, and this point was first considered to be the logical division. More work, however, brought to light the widespread condition of a lime series somewhat lower in the sections, shown on the cross-sections by line B–B. This series is definitely marine and is thought to be equivalent to the limes from which the Sundance fauna came. Good exposures of this lime are found at Hyattville, Bud Kimball, No Wood, and on the southeast end of the Big Horn ranges. A limestone occurring in a similar position on the Rattlesnake Mountains is evidently the same, as is also one occurring at Alcova and locally called the Alcova limestone. No fossils were found in this lime series at the south end of the Big Horns or on the Rattlesnake Mountains, but a thorough search was not made at the time, and later search may prove more satisfactory. We have, how-

[1] E. B. Branson, "Origin of the Red Beds of Western Wyoming," *Bulletin Geol. Soc. Amer.*, Vol. 26, June, 1915.

ever, an unofficial report of a Jurassic fauna from the Alcova limestone at Alcova.

The widespread conditions of this lime, and its general relationships, make it a logical place to put the contact between the Triassic and Jurassic in this general area. This is not definitely proved, however, and is given here as a tentative contact until more data have been collected. A later paragraph suggests even a lower contact.

A faunal list of the fossils as given by Dr. Stanton is here included.

FOSSILS OF SUNDANCE AGE FROM PRYOR MOUNTAIN, WYOMING

Stylina? sp. Plentiful beautifully preserved corals
Ostrea strigilecula White
Lima occidentalis Hall and Whitfield?
Modiolus subimbricatus Meek?
Trigonia quadrangularis Hall and Whitfield
Astarte? sp.
Pleuromya subelliptica Meek and Hayden
Nerinea sp.
Quenstedticeras? sp.

Concerning this fauna Dr. Stanton writes as follows:

It has been known for a good many years that there are red strata and gypsum in the Sundance. Fisher's "Geology of the Big Horn Basin" (*U. S. Geol. Survey Prof. Paper 53*, p. 22), published in 1906, describes a section of this kind on Trail Creek, 8 miles northwest of Cody, Wyoming. Similar occurrences have been noted at many places, but it is very likely that in the actual mapping of some areas red beds of Sundance age have been mapped with the Chugwater. It would not be surprising if this has happened in the Big Horn Mountains even in Fisher's report.

The abundant corals in this lot are surprising because as a rule corals are very rare in the American Jurassic. They doubtless belong to an undescribed species, and I am not quite sure of the identification of the genus.

The ammonite has been examined by Doctor Reeside, who agrees with me that it belongs to the Cardioceratidae and that it suggests *Quenstedticeras* rather than *Cardioceras*, though the actual distinctive features are not preserved.

The finding of a Sundance fauna at a considerable distance below the top of the Chugwater proves that the upper portion of this formation is of Jurassic age. It seems logical to place in this zone everything above the widespread lime deposit and associated sands, which in central Wyoming lie at about 350 feet below the top of the Red beds and from 100 to 200 feet below in southern Montana.

Associated with the limes along line B–B there is a rather heavy ridge-forming sand which covers the entire area herein described and is widespread over Wyoming. While we have no definite proof at this time, we believe that these sands will fall in the La Plata group. In this case the base of the Jurassic will be even lower than is indicated by line B–B, and will fall at the base of the sand series, which is associated with the lime along which line B–B is drawn. More field work is necessary to complete this problem and place accurate boundaries.

This zone at the top of the Chugwater is widespread in the state of Wyoming, and added data are needed to determine both the lateral and vertical extent. It is suggested that this zone should, when thoroughly outlined, be given a new name and placed in the Jurassic. It appears to the writers that this would make for simpler stratigraphy than to include these red shales in the typical Sundance, inasmuch as there appears to be a definite break between the two.

GEOLOGICAL NOTES

AREAL GEOLOGY OF CIMARRON COUNTY, OKLAHOMA[1]

The geologic map of Cimarron County, Oklahoma, in the *Oklahoma Geological Survey Bulletin No. 34*, "Geology of Cimarron County," by E. P. Rothrock, needs considerable revision.

Briefly the geologic section exposed in Cimarron County is this:

Recent and Tertiary sediments and lavas
Angular Unconformity
Benton shales and limestones (present in places)
Dakota sandstone (weathers brown)
Purgatoire formation consisting of
    black fossiliferous shale about 30 feet thick
    white sandstone 15 to 50 feet thick
Disconformity
Morrison formation, consisting of
    sandstones, variegated shale, limestones
Exter sandstone
Angular Unconformity
Unnamed variegated shales (absent in places)
Triassic red beds containing
    maroon shales, red and gray conglomeratic sandstones

The Morrison formation of this region was correctly described by Lee[2] in 1901. He also described the massive sandstone just below the Morrison formation and named it the Exeter sandstone (later spelled Exter). He described the angular unconformity at the base of the Exter sandstone, and the red beds below the unconformity, but did not mention the brilliantly variegated shales that in places are present beneath the unconformity above the red beds.

In 1905 Stanton[3] pointed out that the true source of the Comanchean

[1] Published by permission of the chief geologist of The Midwest Exploration Company.

[2] W. T. Lee, "The Morrison Shales of Southern Colorado and Northern New Mexico," *Jour. Geol.*, Vol. 10, No. 1 (1901), pp. 36–58.

[3] T. W. Stanton, "The Morrison Formation and Its Relations with the Comanche Series and the Dakota Formation," *Jour. Geol.*, Vol. 13 (1905), No. 8, pp. 657–69.

fossils found by Lee and others is the black shale about 30 feet thick just beneath the brown Dakota sandstone, and correlated this black shale and white sandstone directly beneath it as a part of the Washita group. These two members comprise what has since been named the Purgatoire formation.

The so-called "Morrison" formation of Rothrock's map in T. 6 N., R. 1 E., his type locality for Cimarron County, and in T. 5 N., R. 1. E, is the unnamed variegated shale beneath the unconformity. This variegated shale is probably Triassic in age. The unconformity is very slightly angular in places; it is strikingly angular farther up Cimarron River in New Mexico.

The "Morrison" as mapped by Rothrock in T. 5 N., R. 2 E., and T. 6 N., R. 2 E., is a part of the true Morrison.

The Exter sandstone, which outcrops in T. 6 N., R. 1 E., and in T. 5 N., R. 1 E., is included by Rothrock in his Purgatoire formation.

Rothrock's Purgatoire formation is largely Morrison, although it includes the true Purgatoire formation, which should appear on the map as a thin band below the Dakota sandstone. The brown Dakota sandstone rests on the dark shale member of the Purgatoire formation. The true Purgatoire formation consists of just two members: a dark fossiliferous shale about 30 feet thick resting on 15–50 feet of white sandstone. The dark shale corresponds to the Kiowa shale of Kansas, and the white sandstone to the Cheyenne sandstone of Kansas. This white Purgatoire sandstone may rest on colored Morrison shale or on similar white Morrison sandstone. The Morrison sandstones are very lensy and non-persistent. At many places the base of the Purgatoire sandstone is marked by a conglomerate consisting largely of well-rounded flint pebbles. At one place along the road between the Sinclair well in Sec. 22, T. 5 N., R. 2 E., and Kenton (on 101 Hill, I think) the conglomerate is more than 10 feet thick. Where the base of the Purgatoire formation is not marked by the conglomerate or by the Morrison shale, it may be identified, approximately at least, by tracing it from a near by area where it is so marked. This is not invariably true of the area north of Boise City around the Ramsey discovery well, where, as on Wolf Mountain, much of the Purgatoire formation is entirely covered by talus. All the limestones, sandstones, and shales beneath the white Purgatoire sandstone and above the Exter sandstone are Morrison and not Purgatoire, and the shales for the most part are variously colored, like Morrison shales elsewhere. In Cimarron County the Morrison formation probably has a larger area of outcrop than any other pre-Tertiary formation.

Several square miles near the northwest corner of T. 4 N., R. 2 E., are covered by Benton shales and limestones, which are mapped by Rothrock as Dakota formation and Purgatoire formation.

The areal geology of Cimarron County on the new Geologic Map of Oklahoma compiled by the U. S. Geological Survey is taken from Rothrock's map.

RONALD K. DE FORD

AMARILLO, TEXAS
May 3, 1927

CONSTRUCTING GEOLOGIC SECTIONS WITH UNEQUAL SCALES

In the construction of geologic sections it sometimes becomes advisable, for the sake of emphasis, to make the vertical scale either greater or smaller than the horizontal scale. Obviously, any departure from the natural scale will introduce a distortion or exaggeration of the dips of the strata involved; the more the vertical scale is exaggerated, the steeper the inclination of the plotted strata must be in order that the actual depth to a given stratum may be scaled directly from the section.

With a section drawn to natural scale, that is, with both vertical and horizontal scales alike, the dips are plotted as measured in the field, but if the section is constructed with a vertical scale, say twice as great as the horizontal, the plotted dips of the strata become much greater than the observed dips.

The mathematical relation between the actual dip and the dip as plotted on the section may be formulated as follows:

Let v and h represent, respectively, the vertical and horizontal scales of the section; D, the observed dip of the strata; and D', the plotted dip. Also let the ratio of the scales, v/h, be represented by r.

Then from Figure 2 it will be seen that

$$(y/x) \tan D' = (vy/hx) \tan D \ ,$$

or, replacing v/h by its equivalent, r, we have

$$\tan D' = r \tan D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Equation 1 may be written

$$\log \tan D' = \log r + \log \tan D$$

in which form it may readily be charted on an alignment diagram.

Figure 1 is a chart for this equation. The left-hand scale denotes the observed dip, D; the center scale, the ratio r; and the right-hand scale,

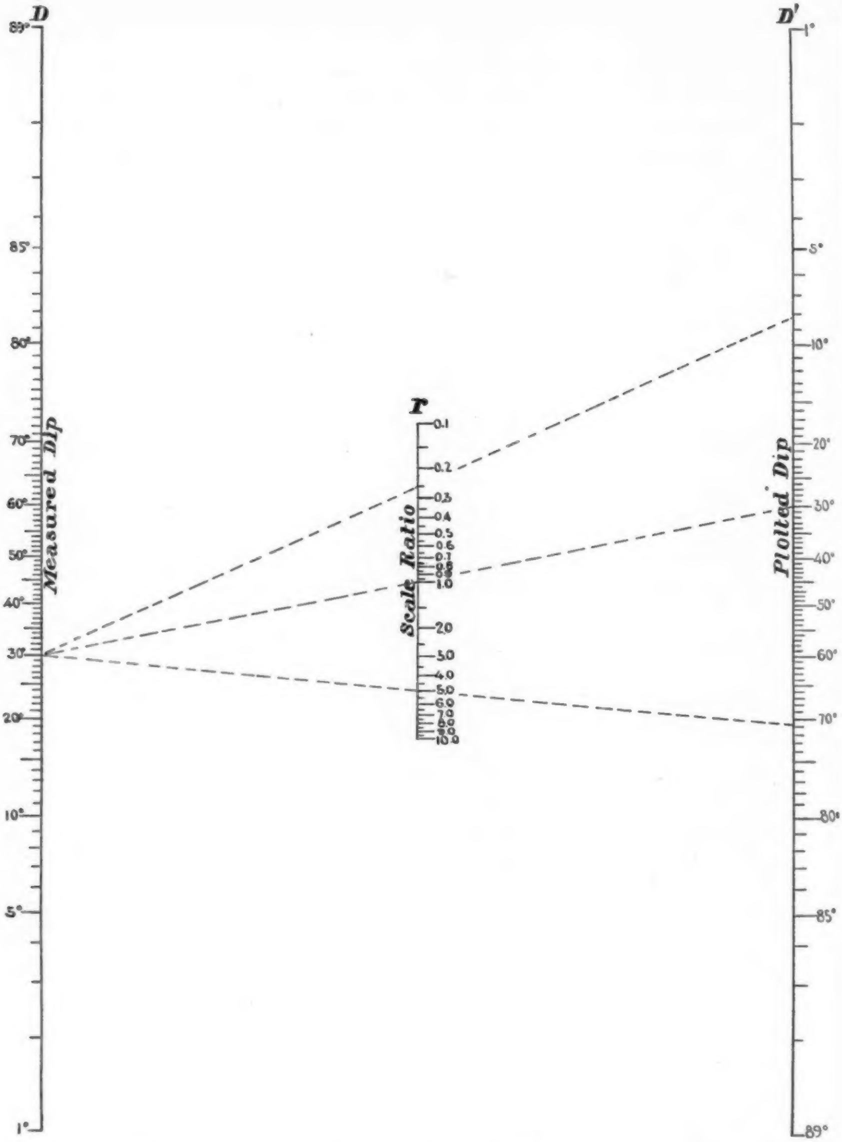

FIG. 1.—Alignment diagram for determining dips on geologic sections drawn to unequal scales

the dip, D', as it would be plotted on the section. The chart embraces all values of dip from 1° to 89° and all scale ratios from 0.1 to 10.0, inclusively.

All that is necessary in determining the plotted dip is to draw a straight line from the point indicating the measured dip on the left-hand scale, through the scale-ratio point on the middle scale, to an intersection with the right-hand scale, where a corresponding value for the plotted dip will be found.

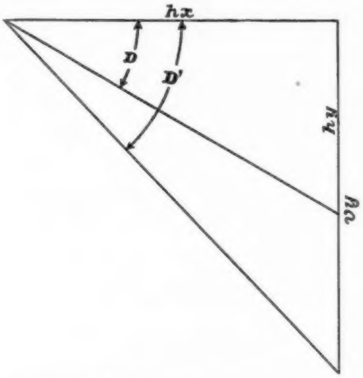

FIG. 2.—Relation of observed dip, D, to plotted dip D'.

For example, suppose the observed dip of the strata is 30°. The vertical scale of the section is 1,000 feet per inch and the horizontal scale 5,000 feet per inch. The ratio, r, is therefore 5.0. A straight line from the 30° mark through 5.0 on the center scale cuts the scale of plotted dip at approximately 70°45′, which is correct within 10 minutes.

Similarly, if the scale ratio is 1.0 there is no distortion of dip and the line through 1.0 cuts the right-hand scale at 30°. But if the vertical scale is only one-fourth the horizontal scale, a line from 30° through $r=0.25$ will cut the right-hand scale at 8°15′, which is the dip to be plotted on the section.

JOHN MELHASE

BERKELEY, CALIFORNIA
May 2, 1927

AN OIL SEEP IN THE FOLDED APPALACHIANS

For nearly twenty years an oil seep has been known in Powell Valley in Lee County in the extreme southwestern part of Virginia. The seep is on the farm of Mr. Kale Bayless, 2 miles east-southeast of the village known as Rose Hill. Mr. Charles Butts, of the United States Geological Survey, made a brief examination of the area in May, 1923, and in July the Survey issued a short memorandum[1] for the press describing the occurrence.

[1] "Oil in Lee County, Virginia," *U. S. Geol. Survey Memorandum for the Press*, July 3, 1923.

Powell Valley is a northeastward extension into Virginia of the Great Valley of Tennessee. In Virginia it terminates in the vicinity of Big Stone Gap. It is largely a rolling lowland, 1,500 to 1,800 feet above sea-level, with an average width of 6 miles, drained by Powell River. On the west it is bounded by the precipitous, monoclinal Stone (Cumberland) Mountain, and on the east by the monoclinal Wallen Ridge of gentler slopes. The valley is underlain by shale and limestone, and agriculturally is one of the richest parts of southwest Virginia.

The following stratigraphic section for the region is adapted with slight modification from Butts:

STRATIGRAPHIC SECTION, POWELL VALLEY

	Thickness in Feet
Pennsylvanian	
Lee formation	1,650
Conglomerate, sandstone, and shale with coal beds	
Mississippian	
Pennington formation	500
Shale, limestone, sandstone	
Newman limestone	500
Limestone and shale above, with oölitic limestone below	
Maccready formation above and Price sandstone below	300
Green shale and brown sandstone	
Devonian	
Black shale	500
(Probably includes Big Stone Gap, Portage, and Genesee shales)	
Silurian	
Clinton formation above and Tuscarora sandstone below	500–600
Massive quartzose sandstone below, with shale, sandstone, and iron ore beds above	
Ordovician	
Sequatchie formation (Upper Cincinnatian)	200+
Red sandstone, sandy shale, red and buff limestone	
Reedsville shale (Lower Cincinnatian)	600+
Shale and limestone	
Chickamaugua limestone	1,750
Includes Catheys and Cannon limestone (Trenton), Lowville and Upper Black River limestone, and Stones River limestone (Chazy)	

	Thickness in Feet
Ordovician and Cambrian	
Knox dolomite (Beekmantown and Upper Cambrian)....	2,800+
Thick beds of dolomite with blue magnesium limestone and chert layers	
Cambrian	
Nolichucky shale above, Marysville limestone, Rogersville shale, and Rutledge limestone below........	1,400–1,500
Yellowish shale and blue-ribbony limestone	
Russell formation....................................	1,000+
Shale, sandstone, and limestone with some red layers	

The western flank and crest of Stone Mountain are composed of the Lee formation, and its eastern flank and the foothills are underlain by Mississippian and older formations. The valley is floored chiefly by Upper Cambrian and Ordovician formations, and Wallen Ridge on the east is largely of Ordovician and Silurian strata.[1]

Structurally Powell Valley is a broad anticline. This great fold, named the Powell Valley anticline, has its northeastern termination in the southeastern part of Wise County northeast of Lee County and extends thence southwest as far as Jacksboro, Tennessee, where it is cut off by the Jacksboro fault. It is generally a single, broad fold, but in places is composed of several smaller anticlines or narrow faulted strips developed therefrom; in width it ranges from five to twelve miles, with an average of seven or eight miles. In Lee County Stone Mountain constitutes the western limb of the fold, the axis of the fold being two miles southeast of the crest of the mountain. The fold is unsymmetrical, the strata on the eastern limb dipping gently southeastward, whereas in Stone Mountain the strata are nearly or quite vertical. The strata flatten out within a short distance northwest of the foot of Stone Mountain, to form the southeast limb of the Middlesboro syncline,[2] a broad syncline lying between Stone and Pine mountains west of Powell Valley.

The structure of the Powell Valley anticline is complicated by overthrust faulting in which the older Cambrian and Ordovician formations have been driven across the fold northwestward over the Silurian rocks. Mr. Butts considers the length of the mass which has been overthrust to be about 115 miles and the width 20–25 miles. The thrust plane evidently terminates in Pine Mountain, possibly passing into the Pine Mountain

[1] *Estillville Folio, U. S. Geol. Survey, Folio No. 12.*

Geologic Map of Western Virginia in *Va. Geol. Survey Bull. 23*, 1922.

[2] Albert W. Giles, "The Geology and Coal Resources of the Coal-bearing Portion of Lee County, Virginia," *Va. Geol. Survey Bull. 26* (1925), p. 39.

fault. Beneath the thrust plane the Silurian is of unknown extent but may continue westward into the Middlesboro syncline and eastward as far as Wallen Ridge or beyond (see section *B–B′* of Fig. 1).

The axis of the Powell Valley anticline, with its flexed overthrust sheet, extends southwest parallel to Stone Mountain and Wallen Ridge, passing about $\frac{1}{2}$ mile west of the oil seep. Near the axis the dip is only about 5° in both directions, but increases to 20° or more farther out on the flanks of the fold, and in local belts on the flanks it may increase to 90°.

The profound erosion to which the higher parts of the anticline have been subjected has completely removed the overlying Cambrian and Ordovician rocks in places, forming fensters in which the overridden Silurian rocks beneath are exposed. The oil seep is located in such a fenster, and 2–3 miles farther southwest another fenster occurs, where iron ore, probably Clinton, has long been mined. The Rose Hill fenster is a little valley about 1 square mile in area, floored by Clinton rocks, but with slopes rising 300 feet or more above the bottom of the valley, and composed of Knox dolomite above and older Upper Cambrian limestone below. The structure of the Clinton rocks in the fenster is anticlinal, according to Mr. Butts, with strike approximately west-northwest, or at nearly a right angle with the main anticlinal axis of Powell Valley. Thus the fenster with its oil seep lies near the intersection of the crest of the Powell Valley anticline and the transverse anticline affecting the Clinton rocks.

An old dug well located near the axis of the fold in the Clinton rocks has at times yielded several gallons of oil. However, no effort was made to drill for oil until late in 1922 or early in 1923, when a well was drilled to a depth of 303 feet. The driller's log follows:

> Started through gray shale and went through this to a depth of 71 feet, when from 18 to 24 inches of green sand was found with a good showing of oil; then to depth of 185 feet greenish-gray shale was found. A green sand of about 4 feet followed, with good showing of oil. The well was left over for two days and one night, during which time oil rose and overflowed casing. After going through this sand, I found red shale to depth of 220 feet, then found 9 feet of dark oil-bearing sand. This sand was apparently full of oil but very hard, and oil did not flow from this sand; then found red shale for a distance of about 30 feet, then a very green shale to a depth of 285 feet, then went into a gray sand 18 feet, which was brittle, not hard like 9-foot sand, and was full of oil. Every bailer dropped into hole to clean the well would come out one-half to two-thirds full of oil. After going through this sand, salt water was found at depth of 303 feet which rose in casing to a height of 200 feet.[1]

[1] "Oil in Lee County, Virginia," *U. S. Geol. Survey Memorandum for the Press*, July 3, 1923.

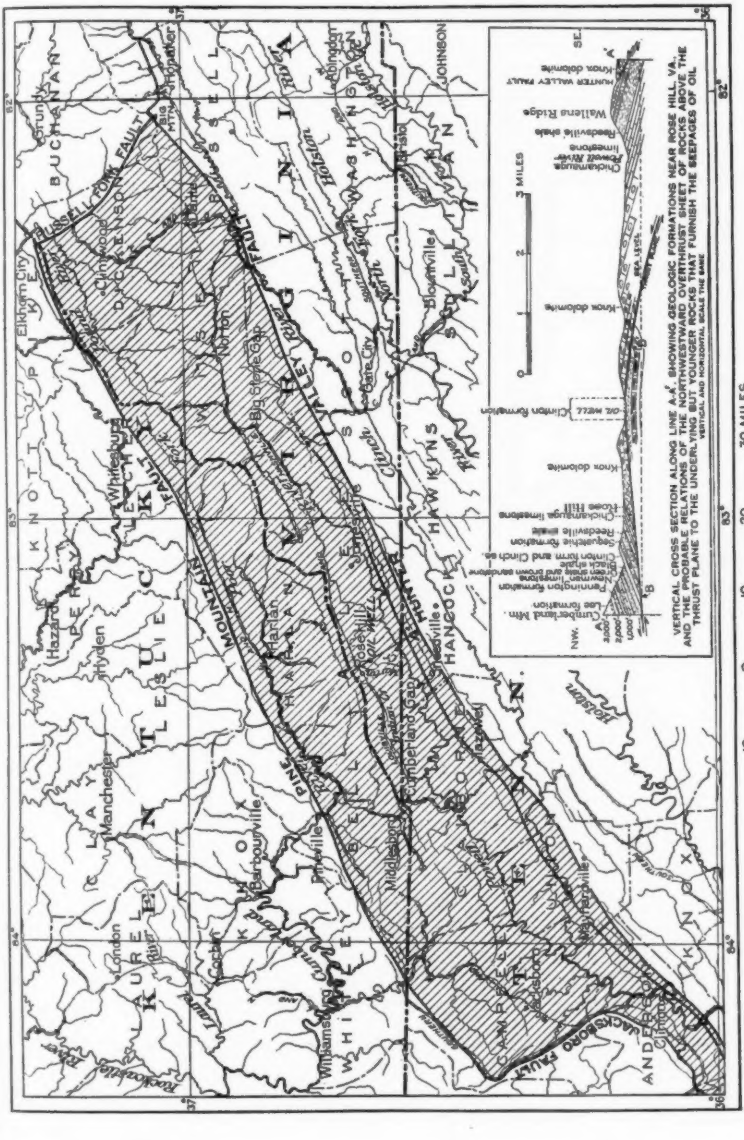

FIG. 1.—Map of the faulted and overthrust block in southwestern Virginia and adjacent parts of Kentucky and Tennessee. Reproduced from "Oil in Lee County, Virginia," *U. S. Geol. Survey Memorandum for the Press*, July 3, 1923.

During the spring of 1927 another well was drilled to a depth of about 400 feet and was reported to be yielding four or five barrels a day, but the hole was lost due to overshooting. At the present time another well is being drilled. Mr. Butts regards the most favorable locality for test drilling to be within a mile or so east, west, northeast, and southwest from the oil seep. The shallow depths necessary to penetrate the Clinton make the test drilling relatively inexpensive. At distances of a mile southeast or northwest of the main axis of the Powell Valley anticline the depth to the Clinton, if it is present, probably will not exceed 1,500 feet. The fenster 2–3 miles southwest of the Rose Hill oil seep indicates that the Clinton is near the surface between the two localities.

A sample of the oil submitted by Representative John M. Robison, of Kentucky, was analyzed by E. T. Erickson, of the United States Geological Survey.[1] He reported:

The oil sample, about 115 cubic centimeters in volume, appeared low in viscosity, opaque to transmitted light, dark green by reflected light, and emitted a kerosene-like odor. Specific gravity of 0.815 at 23° C. (equivalent to 41.8° Baumé). A slight quantity of water was noted in the bottom of the sample container.

One hundred cubic centimeters of the oil sample gave the following results of distillation at atmospheric pressure by the Engler-Abbelohde method. The first drop of distillate appeared in the container at 34° C.

DISTILLATION TEST OF POWELL VALLEY OIL

	Volume of Distillate Fractions (cu. cm.)	Total Volume (cu. cm.)
34° C.–100° C.	6.0	6.0
100 –125	7.0	13.0
125 –150	6.5	19.5
150 –175	6.5	26.0
175 –200	5.0	31.0
200 –225	5.5	36.5
225 –250	6.5	43.0
250 –275	7.0	50.0
275 –300	7.5	57.5
300 –325	6.5	64.0
325 –350	6.0	70.0
350° C. to near 375° C.	27.0	97.0
Coke	2 gm.	

In its properties the oil is closely allied to some of the western Pennsylvania oils. Farmers living in the vicinity are reported to have used the

[1] *Ibid.*

oil for many years for lubricating purposes with very satisfactory results.

The occurrence is of unusual scientific interest because of its location in the folded Appalachians, where the possibliity of obtaining oil and gas in commercial quantities is generally regarded as slight. Although the commercial possibilities of this particular area remain to be demonstrated, it is likely that no more than a small production, at best, can be hoped for.

ALBERT W. GILES

FAYETTEVILLE, ARKANSAS
May 24, 1927

Country or Region		Geologic Province	Age of the Oil-Bearing Strata																	
			Pre-Cambrian	Cambrian	Ordovician	Silurian	Devonian	Mississippian	Pennsylvanian	Permian	Triassic	Jurassic	Comanchean	Cretaceous	Eocene	Oligocene	Miocene	Pliocene	Pleistocene	Recent
North America	Eastern	Appalachian Fields		Gas	Gas	Gas	●	●	○											
		Ontario			○	●	●													
		Cincinnati Arch			●	●	○	●	○											
		Illinois, S.W. Indiana and part of W. Kentucky			○	○	○	●	●											
	Mid-Continent	Kansas and N. Oklahoma			●			●	●	○										
		Texas Panhandle							⊙	●										
		S. Oklahoma and N. Cent. Texas (Bend and Red Beds)						●	●	○										
		W. Texas and S.E. New Mexico								●										
		Gulf Cretaceous (N.E. Texas, N. Louisiana and S. Arkansas)											○	●	○					
		Gulf Coast and S.W. Texas													○	●	●			
	Rocky Mountains	Rocky Mountain Fields (Montana, Wyoming, Colorado, New Mexico)							○	○	○	○		●		○				
		Alberta-Mackenzie					○						○	●						
	Pacific Coast	Los Angeles Basin													○	○	●	○		
		Ventura-Santa Barbara															●			
		San Joaquin Valley												○	○	○	●	○		
		S. Alaska										○					⊙			
		N. Alaska												⊙						
	Mexico	N. Mexico (Panuco etc.)											●	○						
		S. Mexico (Tuxpan etc.)											●	○						
		Tehuantepec															●			
		Lower California															○			
South America	Venezuelan Region	Maracaibo Basin												○	⊙		●			
		E. Venezuela															○			
		Trinidad												○			●	⊙		
	Colombia	Caribbean Colombia														○	●			
		Magdalena Valley													⊙	⊙	●			
		Ecuador													●					
		Peru													●					
		Bolivia										○								
		Argentine										○		⊙			●			
Europe, N. Africa and W. Asia	W. Europe	Great Britain						○												
		Alsace (France)														●				
		Hanover (Germany)										●		●						
		Italy													○		○	○		
		Sicily												○			○			
	Carpathian Fields	Poland (Galicia)												●	●	●	●			
		Roumania														●	●	○		
	Russia	Caucasian Russia														●	●			
		Ural-Emba Basin												○						
		Turkestan												●						
		Petchora-Ukhta				○														
		Sakhalin and N. Siberia													Tertiary					
		Persia															●			
		Mesopotamia															○			
		Palestine and Syria												○			○			
		Egypt												○			●			
		Algeria and Morocco												⊙			○			
Burma and Oceanica		Burma, Assam and E. Bengal															●			
		Punjab													⊙					
		Japan and Formosa															●			
		Sumatra															●	●		
		Java															●			
		Borneo															●	●		
		Philippine Islands													Tertiary					
		China																		
		Australasia																		
		New Zealand															○			

F. Julius Fohs, Oil Geologist, New York

● Major production ○ Minor or prospective production ⊙ Age of production in doubt

STRATIGRAPHIC DISTRIBUTION OF PETROLEUM

Chart showing the stratigraphic distribution of petroleum as found in the producing and prospective fields of the world, with information available as to the geologic age of important foreign oil deposits. Prepared by F. Julius Fohs in connection with a course of lectures on oil geology given by him at Columbia University, 1927.

REVIEWS AND NEW PUBLICATIONS

Sur le degré géothermique dans quelques puits à pétrole en cours de forage à Bitkow. By H. Arctowski. Inst. de géophys. et de météorol. de l'université de Lwow (Lemberg, Poland), Commun., No. 4 (1923), 8 pp. 8 vo.

Essais de détermination du degré géothermique dans le puits Ratoczyn 5 à Boryslaw. By H. Arctowski. *Ibid.*, No. 5 (1923), 6 pp. 8 vo.

Nouvelles recherches sur les gradients thermiques dans les puits à pétrole de Boryslaw, Krosno et Bitkow. By H. Arctowski. *Ibid.*, No. 7 (1924), 45 pp. Review of German abstract, *Geologisches Zentralblatt*, Leipzig, Vol. 34, No. 11 (March, 1927), p. 492.

Description of apparatus and research methods, study of disturbing influences, tables, and graphic representations of numerous measurings of the earth temperature to depths of 1,500 meters. Comparison of the results obtained from measurings in upper Silesia, Roumania, West Virginia, and South Africa.

Charles Ryniker

Die Geologie und die Salzdome im südwestlichen Teile des Persischen Golfs. By R. K. Richardson. Dissertation at Heidelberg. Verhandlungen des Naturhistor.-medizinischen Vereins, N.F. 1926, Vol. 15, pp. 1–49. 5 plates. Review of German abstract, *Geologisches Zentralblatt*, Leipzig, Vol. 34, No. 11 (March, 1927), p. 507.

The author worked as geologist for the Anglo-Persian Oil Company in the winter of 1921–22 in the region of the Gulf of Persia.

He distinguished a younger group of sediments ranging in age from Upper Cretaceous to Quaternary with a characteristic fauna, and an older, non-fossiliferous group of sediments composed of deposits of different ages—in any case older than Upper Cretaceous.

Numerous salt domes were found along the Gulf Coast, in the interior of the coast region, and on the adjoining islands. Their outline is more or less circular with a diameter from 5–10 kilometers. The salt domes generally appear in the axes of the anticlines, selecting the less resistant portions for their intrusion. In most of the cases the salt mass broke through the overlying sediments, exposing the younger beds in vertical or steep positions along the contact zone. The author believes that these salt domes are the result of normal tectonic movements.

Charles Ryniker

Tulsa, Oklahoma
May 23, 1927

The Scientific Principles of Petroleum Technology. By LEO GURWITSCH. Translation and revision 1925 edition by HAROLD MOORE. 464 pp., 13 diagrams, 8 plates. New York: D. Van Nostrand Company, 1927. $8.00.

The first edition of this treatise was published in 1912, but it has not heretofore been available in the English language. Mr. Moore, the translator, is a consulting petroleum technologist in London. The author, Dr. Leo Gurwitsch, is a professor of the University and the Technical High School at Baku.

The purpose of the book may best be stated in the author's own words:

> The task which I set before me in writing this book was to give a general view of the scientific side of the subject to the chemist interested in the petroleum industry. In consequence of all practical questions of technology (such as the methods of carrying out the chemical processes, constructive details, etc.) have been entirely left out of consideration. An exhaustive and complete compilation of what had appeared in the literature was the less my object, as at the time I commenced this task the magnificent work of Engler and Hofer had been announced and had in part appeared. I have, however, endeavored to treat what is essential thoroughly and, as far as possible, critically, in some cases with illustrations from my own experience.

The book is divided into three parts: (1) raw materials, (2) manufacturing, (3) products. In the first part the chemical and physical properties of petroleum are described; the second part covers the distillation and refining of petroleum; and in the third part, the principal commercial products are described.

As was to be expected, the subject matter chiefly concerns Russian oils and Russian practices but includes many references to European literature and some to American literature. To the American technologists the chief merits are the European references and the European viewpoint. Our own petroleum literature, particularly with reference to our own practical problems, is so rich that we are inclined to overlook the valuable contributions in other languages. There are many exceedingly valuable references, and it would pay every American technologist interested in the phases of petroleum technology covered in this publication to study it carefully for new materials and new viewpoints.

JAMES O. LEWIS, *Petroleum Engineer*

TULSA, OKLAHOMA
June 1, 1927

Grundlagen der Erdbebenkunde ("Elementary Seismology"). By B. GUTENBERG. "Sammlung Borntraeger," Bd. 12. Berlin: Gebrüder Borntraeger, 1927. Pp. 189. M. 6.60.

This brief introduction to the study of earthquakes and their recording gives a presentation of the results of seismology up to date such as is not available to the reviewer's knowledge, in books published in English. It is of interest to petroleum geologists because the principles of recording artificial sound-waves to locate oil fields by determination of structure are similar to those of recording

earthquakes. The deflection of longitudinal and transverse waves by the central core of the earth is comparable to that by salt domes or by strata differing in physical properties from adjacent strata.

SIDNEY POWERS

RECENT PUBLICATIONS

VIRGINIA

"Oil and Gas Possibilities at Early Grove, Scott County, Virginia," by Charles Butte. Prepared in co-operation with the *U. S. Geol. Survey. Bull. 27, Virginia Geological Survey,* University, Virginia, 1927. 18 pp.; 2 figs.

GENERAL

"Methods and Tools for Removing Paraffin from Flowing Wells," by C. E. Reistle, Jr. *Report of Investigations Serial No. 2802, U. S. Bur. of Mines,* Washington, D.C. April, 1927. Free distribution.

"Sources and Distribution of Major Petroleum Products, Atlantic Coast States, 1925," by E. B. Swanson. *Information Circular No. 6031, U. S. Bur. of Mines.* April, 1927. Free.

Technical Paper 404, by C. E. Reistle, Jr. U. S. Bur. of Mines. A paper on analyzing underground waters in oil fields. Obtainable from the Superintendent of Documents, Washington, D.C. Price, $0.05.

Salt Dome Map of Louisiana, compiled by N. E. Dufilho. Minerals Division, State Dept. of Conservation, Shereveport, Louisiana. Photostatic copy of U. S. Geol. Survey base map with locations and names of salt domes added. 20×22 in. Price, $1.25.

L'Annuaire du Pétrole ("The Yearbook of Petroleum"), edited by Ed. Mauris. Preface by Jammy Schmidt, deputy, former under-Secretary of State in Finance. Lists and describes producing companies, showing organization, officers, production, capital, activity, etc. Address, 60, Boulevard de Clichy, Paris. XVIII^e. 1927. Pp. 715. Price, 45 fr.

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The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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Albert W. Giles, Hugh D. Miser, J. P. D. Hull
Walter S. Field, Wichita, Kan.
R. J. Riggs, Arthur E. Stander, R. J. St. Germain
Gaylord G. Frazier, Russell, Kan.
Anthony Folger, George H. Norton, W. B. Case
Alan James Galloway, Bakersfield, Calif.
Art. R. May, E. F. Davis, John G. Burtt
Robert M. Gordon, Pittsburgh, Pa.
Roswell H. Johnson, K. C. Heald, R. S. Knappen

S. F. Harris, Amarillo, Tex.
Raymond M. Carr, Wesley G. Gish, G. E. Ebmeyer
F. Mabry Hoover, Mountain View, Okla.
Charles N. Gould, A. F. Morris, Luther H. White
Harry Winston Hull, Wichita, Kan.
Frederic G. Holl, H. L. Hummel, William L. Ainsworth
Harry W. Imholz, Dallas, Tex.
Ulrich R. Laves, W. H. Whittier, Angus McLeod
Esther Smith Johnston, Denver, Colo.
A. E. Brainerd, Ross L. Heaton, W. C. Toepelman
John J. King, Austin, Tex.
Fred M. Bullard, F. L. Whitney, Frederic W. Simonds
Frank R. Kittredge, Shawnee, Okla.
Noel Evans, E. L. Roark, Glenn C. Clark
George L. Knox, Whittier, Calif.
George M. Cunningham, G. C. Gester, E. M. Butterworth
Joseph M. McMillan, Jr., Bartlesville, Okla.
John R. Reeves, Charles C. Hoffman, J. M. Nisbet
Cyrus W. Magalis, Dallas, Tex.
C. E. Yager, Jr., David Donoghue, H. B. Fuqua
H. Claire Matheny, Wichita Falls, Tex.
E. F. Scharmm, M. M. Garrett, F. K. Foster
Charles W. Miller, Sapulpa, Okla.
Charles E. Decker, A. J. Williams, V. E. Monnett
Clark D. Millison, Wichita, Kan.
Charles E. Decker, V. E. Monnett, A. J. Williams
James K. Murphy, Tulsa, Okla.
A. W. Duston, Luther H. White, Harry H. Nowlan
Merrill A. Neel, Ponca City, Okla.
George W. Artman, V. E. Monnett, C. E. Decker
L. E. Paine, Ardmore, Okla.
Carl W. Clarke, Frank Gouin, Charles E. Clowe
Joe C. Palmer, Houston, Tex.
C. E. Yager, David Donoghue, F. B. Plummer
George D. Putnam, Winfield, Kan.
Charles E. Decker, V. E. Monnett, A. J. Williams
Wayne C. Rauch, Colorado, Tex.
B. L. Laird, Leonard W. Orynski, Henry J. Hawley
Wallace E. Richmond, Jr., Bradford, Pa.
John M. Herald, J. B. Umpleby, Jerry B. Newby
Cecil D. Robinson, El Dorado, Ark.
Albert W. Giles, Hugh D. Miser, George C. Branner

C. Bjarne Rossebo, Okmulgee, Okla.
F. W. Bartlett, J. B. Leiser, George W. Artman
Horace L. Scott, Norman, Okla.
Charles E. Decker, V. E. Monnett, A. J. Williams
Richard E. Sherrill, Fort Worth, Tex.
William A. Thomas, Paul B. Hunter, W. R. Berger
Harold L. Strader, Cheyenne, Wyo.
J. J. Galloway, W. O. George, Frank B. Notestein
DeWitt E. Taylor, Los Angeles, Calif.
Art. R. May, E. F. Davis, John G. Burtt
George Dewey Thomas, Shreveport, La.
Chester C. Clark, W. C. Spooner, N. B. Winter
Benton Reid Vernon, Shreveport, La.
W. C. Spooner, A. L. Selig, A. F. Crider
Edwin A. Wahlstrom, Denver, Colo.
Anthony Folger, George H. Norton, W. B. Case
Ray Youngmeyer, Wichita, Kan.
Charles E. Decker, V. E. Monnett, R. C. Moore

FOR TRANSFER TO ACTIVE MEMBERSHIP

Thomas H. Allan, Russell, Kan.
Anthony Folger, George H. Norton, Harold T. Morley
Bernerd W. Blanpied, Shreveport, La.
L. C. Snider, Roy A. Reynolds, E. W. Hummel
Leo R. Fortier, Wichita, Kan.
F. W. Bartlett, T. K. Harnsberger, E. L. Jones, Jr.
Lawrence R. Hagy, Amarillo, Tex.
Charles E. Decker, J. V. Howell, W. R. Berger
Roy T. Hazzard, Shreveport, La.
S. E. Mix, W. C. Spooner, A. L. Selig
Merle C. Israelsky, Shreveport, La.
John S. Ivy, W. C. Spooner, J. Y. Snyder
Norman Meland, Oklahoma City, Okla.
J. B. Umpleby, D. W. Ohern, W. C. Kite
William J. Nolte, Wichita Falls, Tex.
J. V. Howell, J. P. D. Hull, Harald W. C. Prommel
Ernest Aloysius Obering, Shreveport, La.
Chester C. Clark, W. C. Spooner, A. F. Crider
John E. Van Dall, Bartlesville, Okla.
Raymond M. Carr, Wesley G. Gish, Harry J. Brown
Virgil L. Whitworth, Dallas, Tex.
Joseph M. Wilson, Leon J. Pepperberg, Frederic H. Lahee

MEETING OF EXECUTIVE COMMITTEE, TULSA, MAY 20

At the call of President Gester, the Executive Committee met in the Hotel Mayo, Tulsa, May 20. Members of the committee present were G. C. Gester, president, Luther H. White, vice-president, David Donoghue, secretary-treasurer, and John L. Rich, editor.

AMENDMENTS TO THE CONSTITUTION

The ballot committee, composed of Luther H. White and A. L. Beekly, appointed by past-President Alex W. McCoy, reported the following results of the letter ballot on the three proposed amendments to the Constitution which were recommended by the business committee at the Tulsa meeting, March 25:

Proposal 1. For, 559. Against, 92. Disqualified, 15.

Proposal 2. For, 581. Against, 74. Disqualified, 15.

Proposal 3. For, 529. Against, 126. Disqualified, 15.

Total number of ballots returned, 670. Minimum number returned ballots required by the Constitution, 574. In accordance with the large majorities shown, President Gester declared the Constitution amended as follows (in order of the proposals as stated):

ARTICLE IV, SECTION 1. The officers of the Association shall consist of a president, a first vice-president, a second vice-president in charge of finances, and a third vice-president in charge of editorial work. These, together with the retiring president, shall constitute the executive committee and managers of the Association.

ART. IV, SEC. 2. The officers shall be elected annually from the Association at large by written ballot deposited in a locked ballot box by those active members present at the annual meeting, who have paid their current dues and are otherwise qualified under the Constitution.

ART. III, SEC. 2. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, shall be eligible to associate membership in the American Association of Petroleum Geologists, provided that at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing or shall be engaged in geological work. The executive committee shall advance from associate to active membership those associates who have, subsequent to election, fulfilled the requirements for active membership, without the formality of application for such change.

THIRTEENTH ANNUAL CONVENTION

The Executive Committee accepted the invitation of the Pacific Section to hold the thirteenth annual meeting in San Francisco, Wednesday, Thursday, and Friday, March 21, 22, and 23, and in Los Angeles, March 24 and 25, the

business and technical sessions to be in San Francisco and special features of entertainment and sight-seeing to be continued at Los Angeles during the week-end. Look for further announcements!

GENERAL BUSINESS COMMITTEE

The resolution providing for a General Business Committee passed by the Association in the business meeting of March 25, 1927 (see this *Bulletin*, May, 1927, pp. 549–50) was given consideration; and representation was provided on the basis of each fifty active members, more or less, in each district.

DISTRICTS AND REPRESENTATIVES

District	Number of Representatives	Term of Each Representative (Years)	States in District
Houston	1	1	Texas
Fort Worth	1	2	Texas
Dallas	1	3	Texas
Amarillo	1	3	Texas
Wichita Falls	1	3	Texas
San Angelo	1	1	Texas
Tulsa	1 1 1	1 2 3	Oklahoma
Enid	1	3	Oklahoma
Ardmore and Oklahoma City	1	2	Oklahoma
Wichita	1	2	Kansas, Nebraska, North Dakota, South Dakota
Shreveport	1	2	Louisiana, Arkansas, Alabama, Florida, Mississippi, Georgia, South Carolina
Rocky Mountain	1 1	1 3	Colorado, New Mexico, Wyoming, Montana, Arizona, Utah, Idaho
Pacific Coast	1 1 1	1 2 3	California, Nevada, Oregon, Washington
New York	1	1	New York, New Jersey, New England States
Capital	1	3	Washington, D.C., Maryland, Virginia, North Carolina, Delaware
Appalachian	1	1	Pennsylvania, Ohio, West Virginia, Kentucky, Tennessee
Great Lakes	1	1	Illinois, Indiana, Michigan, Missouri, Iowa, Wisconsin, Minnesota
South America	1	2	....
Mexico	1	1	....
Canada	1	2	....

The term of each representative was determined by lot, and the number of representatives was allotted on the basis of a statement prepared by the business manager showing the addresses of active members by cities and states.

It is recommended that each district elect its representatives or representative on or before September 15, 1927.

It is suggested that a petition system be used whereby the name of each candidate is placed on a separate petition and signatures obtained indorsing this particular man for member of the General Business Committee from the ——— district, for a term of —— years, and that these be sent to the business manager, Box 1852, Tulsa, Oklahoma, who will verify the signatures and report to the Executive Committee.

The resolution provides that in case a district fails to elect representatives the same be elected by the Executive Committee.

Each district has been notified by letter from Headquarters and requested to proceed with the local elections. The twenty districts and twenty-five representatives are distributed as shown in the foregoing table (p. 775).

JOURNAL OF PALEONTOLOGY

The Paleontologic Group of the American Association of Petroleum Geologists is now issuing its own publication containing papers on paleontology and sedimentary petrography with special reference to microscopic methods. The Association *Bulletin* is no longer printing papers on these subjects. An announcement of the new publication follows.

The *Journal of Paleontology* is the official publication of the Society of Economic Paleontologists and Mineralogists.

The Society is an organization whose object, as stated in Article II of its constitution, is "to promote the science of stratigraphy through research in paleontology and sedimentary petrography, especially as they relate to petroleum geology," and whose membership is composed of members or associate members of the American Association of Petroleum Geologists engaged in such work.

The *Journal of Paleontology* will be devoted to research in paleontology and sedimentary petrography. The paleontological papers will include those pertaining to faunal distribution, stratigraphic index species, description of individual faunas, relation of zones to habitats, etc. Sedimentary petrographical papers will pertain to mineral zones, stratigraphic distribution, provinces of sedimentation, etc. Papers will also be included which pertain to technique bearing on research in paleontology, and sedimentary petrography. In fact, those papers will be included which will in any manner be helpful to those engaged in stratigraphic studies carried on either in the laboratory or in the field.

The *Journal of Paleontology* will be a quarterly publication of approximately 96 pages and 20 plates per number. It will be $6\frac{3}{4}\times9\frac{1}{2}$ inches in size, and will be published by the University of Chicago Press.

Dr. Joseph A. Cushman will be the editor of the *Journal of Paleontology*. Dr. Cushman is one of America's most active micro-paleontologists. He has been engaged in research for many years, and is now one of the world's foremost authorities on the Foraminifera. He will have associated with him an editorial board to assist in matters not in his particular field.

The subscription price to the *Journal of Paleontology* is six dollars ($6.00) per year. Check or P.O. Money Order for the subscription may be sent to Marcus A. Hanna, secretary-treasurer, Society of Economic Paleontologists and Mineralogists, P.O. Drawer C, Houston, Texas.

MORE SUBSCRIBERS TO THE BULLETIN

The business manager sent the following letter to each of the Association districts last month:

Your executive committee has been considering ways and means of increasing the number of *Bulletin* subscribers and Association members. Although our growth since organization in 1917 has been rapid and sustained, it is evident from the inquiries received at headquarters that our field of activity and influence is still wide and open. The A.A.P.G. is now the largest organized body of geologists in the world. It occupies a pre-eminent position in petroleum geology and the geological phases of petroleum engineering and technology. Our *Bulletin* is the accepted publication in these fields of the petroleum industry. Its articles are comprehensive and reliable. Its contributors are leading authorities. The *Bulletin* is becoming known outside of the membership. It now goes to 39 states and 26 foreign countries, thus eliciting contributions on as many different problems and conditions of the industry. Its worth should be more familiar to the profession and to the industry. To the practising geologist and to the operator it is invaluable. To the college or technical library it is a necessity. The work of the Association should be made known more fully. Our list of subscribers and members can be greatly increased to our mutual good.

For the purpose, therefore, of bringing this advantage of our continued growth definitely to the attention of our members, and in order to create effective competition, and to afford a material incentive, one of the members of your committee is generously offering one hundred dollars ($100.00), or a watch costing that amount, to that member who secures the largest number of new subscribers or acceptable applications for membership, or both, in excess of 50, on or before September 15, 1927. Subscriptions are to be for the calendar year, 1927, $15.00. Annual dues, active members, $15.00; associates, $8.00. There is no initiation fee. Associate dues are to be $10.00 in 1928. Subscription and application blanks and a limited number of sample copies of the *Bulletin* will be furnished upon request. Contestants should write their names on one corner of each blank to receive proper credit. This contest is open to active and associate members alike. There are no district or territorial limits.

Memorial

NOAH C. ADAMS

Noah C. Adams died at his home in Tulsa, Oklahoma, April 18, 1927, at the age of thirty-five years. Noah was born at Cane Hill, Arkansas, June 29, 1891. His family was among the pioneers of that section of the state.

Immediately after earning his degree in engineering and geology from the University of Arkansas in the class of 1914, he came to Tulsa and was employed by the Guffey-Gillespie Oil Company. During his connection with this company, he established himself as one of the best field geologists in the Mid-Continent area.

Later he became associated with C. F. Farren and T. J. Wood as geologist and junior partner. This connection proved a profitable one financially and his interests became varied, so that at the time of his death he was a member of the board of directors of the Tulsa Trust Company, Tulsa Lumber Company, and Page Bros. Oil Company, and was vice-president of the Adkay Petroleum Company.

He was a member of Tau Beta Phi, honorary engineering fraternity, the American Association of Petroleum Geologists, and was a 32d-degree Mason, Oklahoma Consistory, Valley of Guthrie.

He is survived by his father and mother, Mr. and Mrs. W. C. Adams of Fayetteville, Arkansas, his wife, Katherine J., a son, Phillip Harrison, and a daughter, Martha Ruth, of Tulsa.

Noah's thorough knowledge of the geology of the Mid-Continent area, combined with his unusually rare judgment, made him stand out as one of the leaders of his profession.

William D. Gray

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

O. L. Brace, formerly situated with the Marland Oil Company at Shreveport, Louisiana, is now at 1801 W. T. Waggoner Building, Fort Worth, Texas.

O. C. Wheeler, until recently stationed at Cartagena, Colombia, with the Tropical Oil Company, has moved to 1410 Monroe Street, Amarillo, Texas, after a hospital illness in Cartagena.

W. Bernoulli is in Venezuela.

Freeman Ward, formerly state geologist of South Dakota, is teaching at Pennsylvania State College, Easton, Pennsylvania.

C. H. Chadwick is teaching in the high school at Catskill, New York.

The Fifteenth International Geological Congress will be held in South Africa in August, 1929.

Joseph Jensen, of Los Angeles, California, is chief petroleum engineer of the Associated Oil Company.

A. W. Duston, of the Independent Oil & Gas Company of Tulsa, spent part of May on an automobile trip through the Mid-Continent district. Mrs. Duston accompanied him.

Charles N. Gould, state geologist, Norman, Oklahoma, plans to have eight field parties at work this summer. Co-operative work is being carried on with the U. S. Geological Survey, the U. S. Bureau of Mines, the Oklahoma State Highway Commission, the University of Oklahoma, and thirty-nine Oklahoma geologists. The Survey library of 9,000 volumes is being rearranged.

Walter M. Small has been working in southwestern Texas.

E. G. Woodruff, consulting geologist of Tulsa, Oklahoma, was in Canada in the interest of clients last May.

J. S. Irwin, chief geologist, assisted by H. N. Hickey, of Frank E. Kistler & Company, Denver, Colorado, examined geological evidence at the Separation Flat structure in the general area of the Little Lost Soldier oil field in Carbon County, Wyoming. This work was in advance of Sullivan core drill tests in that area.

Stanley B. White may be addressed at Box 52, Emporia, Kansas.

H. M. Bayer, geologist for the Gulf Production Company, formerly at Eastland, has moved to Midland, succeeding O. C. Harper, who has resigned. A. C. Nance relieves Mr. Bayer at Eastland.

J. L. Chase moved in May, from Palestine to Abilene, Texas.

Harold W. Haight left the Colorado School of Mines last May and is now located with the Transcontinental Oil Company, Apartado 657, Tampico, Tamps., Mexico.

Donald C. Barton has opened an office in the Petroleum Building, Houston, Texas. He is engaged in consulting work as geologist and geophysicist specializing on salt domes and direction and interpretation of torsion balance and magnetometer surveys.

Harry W. Oborne, 2001 North Cascade Boulevard, Colorado Springs, Colorado, is consulting geologist for the Table Mesa Oil Company and the MacKenzie Oil Company.

A. J. Smith, recently with the Humphreys Corporation at Houston, is now with the Pure Oil Company, Western Building, Amarillo, Texas.

Henry T. Beckwith is no longer connected with the Noble Oil and Gas Company, formerly of Tulsa.

Robert S. Burg, 1119 W. T. Waggoner Building, Fort Worth, Texas, suffered a serious accident in May, when he broke his back by a fall from a tree while engaged in survey work near Brazos, Texas.

W. Z. Miller, consulting geologist in Tulsa, has been working in Colorado.

Julia A. Gardner, of the U. S. Geological Survey, returned to Louisiana and Texas in June for the annual field trip of the Shreveport Geological Society.

S. A. Thompson, of the Vacuum Oil Company, has been working in east Texas.

H. G. Schneider is in charge of geophysical work for the Dixie Oil Company.

Homer R. Montgomery is living at Mineral Wells, Texas. He has resigned from the Marland Oil Company.

Labor-saving devices are being devised by geologists. Jack Doyle, of Shreveport, uses rubber bands for all his contour lines so that daily changes will not be noticed. E. DeGolyer, of New York City, is investigating a jumping balloon, now made in England, so that he can inspect the Seminole fields without wading through the mud. Robert D. Goodrich, of Tyler, Texas, has perfected the stethoscopic method for locating salt domes which is applied each evening to the seismographers when they return from the field.

J. C. Templeton has organized the Geophysical Prospecting Company at Houston.

RALPH A. BRANT and WILLIAM C. ADAMS, of the Shaffer Oil & Refining Company of Tulsa, published in the *Oil and Gas Journal* for March 24, a cross-section of Oklahoma in T. 18 N., from R. 3 to 12 E. The section is drawn through the Cushing field. It shows the correlation of each limestone and sand based on a study of about 170 graphic well logs which are reproduced on a vertical scale of about 300 feet to one inch.

A. L. BEEKLY, chief geologist for the Mid-Continent Petroleum Corporation, Cosden Building, Tulsa, Oklahoma, arranged a field inspection trip by automobile for several officials and department heads of his company through southwestern Texas and eastern New Mexico last May.

LUTHER H. WHITE, chief geologist for J. A. Hull Company, Tulsa, made a business trip to Columbus, Ohio, in May, and upon his return, spoke before the Tulsa Geological Society at its luncheon, May 27, giving his impressions of Ohio geology compared with the geology of Oklahoma.

The Executive Committee of this Association met at the Hotel Mayo, Tulsa, Oklahoma, May 20. Those present were G. C. GESTER, president, LUTHER H. WHITE, vice-president, JOHN L. RICH, editor, and DAVID DONOGHUE, secretary-treasurer.

E. DEGOLYER was in the Mid-Continent region a large part of May.

JACK FROST, petroleum engineer with the U. S. Geological Survey, has established the Big Horn Basin office of the Survey at Thermopolis, Wyoming.

R. T. LYONS, of San Angelo, has charge of land and geological work for Skelly Oil Company in west Texas.

J. T. CUSACK, with headquarters at Forth Worth, has charge of land and geological work for Skelly Oil Company in north-central and east Texas.

R. B. WHITEHEAD, chief geologist for the Atlantic Oil Producing Company at Dallas, was on the speaking program of the fourth annual convention of the National Oil Scouts Association of America in that city, May 23 and 24.

H. W. C. PROMMEL, consulting geologist of Denver, Colorado, has moved to his new offices at 724–25 First National Bank Building.

WALTER MADISON SMALL and Kathleen Hull Harvey announce their marriage on Saturday, the twenty-first of May, nineteen hundred and twenty-seven at New Braufelds, Texas. Mr. and Mrs. Small will be at home after June 15 at Cooperstown, Venango County, Pennsylvania.

JAMES N. HOCKMAN, recently with the Marland Oil Company at Wichita Falls, is now with The Texas Company at Crossett, Texas.

MAX L. KRUEGER is in Venezuela. His address is Apartado 234, Venezuela Gulf Oil Company, Maracaibo.

W. C. MORSE has returned from Massachusetts Institute of Technology to the A. and M. College, Mississippi.

R. H. Smith, recently in charge of the office of W. C. McBride, Inc., at San Antonio, has been transferred to Amarillo, Texas.

Rual B. Swiger of the Roxana Petroleum Corporation has moved from Aspermont to Sonora, Texas.

Chester W. Washburne talked an hour on the "Nature of Normal Faults" before the geological students at the University of Chicago, who responded with two hours of vigorous discussion.

M. B. Schmittou, formerly at Tampico, Mexico, may now be reached care of Standard Oil Company (S. A. Argentina), Edificio Banco Boston, Buenos Aires, Argentina.

Harold N. Hickey has a permanent address at 600 Patterson Building, Denver, Colorado.

Wilson Keyes has moved from Colorado, Texas, and is now with the Simms Oil Company at 412 Rust Building, San Angelo, Texas.

P. G. Russell may be addressed at Box 635, Eastland, Texas.

M. G. Cheney presented a review of his paper on "The History of the Carboniferous Sediments of the Mid-Continent Area," and Theron Wasson gave a moving-picture lecture on "A Recent Trip to Venezuela" before the Tulsa Geological Society, June 4.

The Shreveport Geological Society held its Fifth Annual Field Trip June 11 and 12. Problems of Wilcox and Claiborne Eocene were studied in east Texas counties adjoining northwestern Louisiana. A. F. Crider was chairman of the committee for the trip.